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GEORGE OTIS SMITH, DIRECTOR

BULLETIN 344

THE STRENGTH OF CONCRETE BEAMS

RESULTS OF TESTS OF 108 BEAMS

(FIRST SERIES)

MADE AT THE STRUCTURAL-MATERIALS TESTING LABORATORIES

BY RICHARD L. HUMPHREY

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THE STRENGTH OF CONCRETE BEAMS.

By Richard L. Humphrey.

INTRODUCTION.

SCOPE OF INVESTIGATIONS.

The tests of concrete beams described in this bulletin form a part of a comprehensive series of investigations undertaken by the United States Geological Survey for the purpose of determining the strength of concrete and reinforced concrete.

The work involved in these investigations consists of a study (1) of the constituent materials of concrete, (2) of its strength when molded into various structural shapes, and (3) of the methods by which its maximum strength may be developed through various forms of metallic reinforcement.

Although it is true that concrete possesses but little strength in tension and must be reinforced with metal to resist tensile stresses, it is believed that no study of concrete would be complete without a series of tests establishing its strength without reinforcement.

The tests herein reported indicate that concrete is unsuitable for use under conditions where it must resist tensile stresses, because of the small loads it will sustain and particularly because of the suddenness with which it fails, in striking contrast to the behavior of reinforced concrete, which usually shows a gradual development of cracks preceding failure.

This first series of beam tests covers 144 beams without reinforcement 8 by 11 inches in section and 13 feet long, together with the corresponding compression test pieces, consisting of cylinders 8 inches in diameter by 16 inches in length and of 6-inch cubes. Of these tests those on 108 beams of 12-foot span, with their cylinders and cubes, and those on 108 beams of variable spans, 6 to 9 feet, which were made of the larger part of the 13-foot beams after rupture, are herein reported and comprise all of this series except the 52-week tests.

An attempt has been made to bring out, if possible, the comparative value of gravel, granite, limestone, and cinders for use in concrete; the effect of age and consistency on the strength, as shown by the modulus of rupture of the long and short beams and by the ultimate strength of the cylinders and cubes; and the influence of age and consistency on the stiffness, which is indicated by the unit

elongation of the long and short beams and by the initial modulus of elasticity, as determined by tests of the cylinders.

Three consistencies — wet, medium, and damp — were somewhat arbitrarily chosen, and are described on pages 20–21 in greater detail. Tests were made at the ages of 4, 13, 26, and 52 weeks. There are, then, as indicated in the following table, but two variables—aggregate and consistency—for each age.

Outline of tests of concrete beams.

Aggregate.	Consistency.											
	4 weeks.			13 weeks.			26 weeks.			52 weeks.		
Granite	Wet.	Med.	Damp.	Wet.	Med.	Damp.	Wet.	Med.	Damp.	Wet.	Med.	Damp.
Gravel	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do
Limestone	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do
Cinders	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do	..do

NOTE.—Three beams, three cylinders, and three cubes were made for each variation shown in the table.

METHODS OF TESTING.

The methods of testing beams of 12-foot and variable spans, together with cylinders and cubes, have been described in considerable detail in Bulletin No. 329. It is thought best, however, to repeat and in some cases amplify matter which appears there, as the intelligent interpretation of much of the test data is greatly aided by ready access to an account of the methods of testing that were used.

RESULTS OF TESTS.

No attempt has been made in this bulletin to generalize the results of the tests herein presented, or to draw any conclusions, however warranted they may appear from an examination of the test data. It is hoped that the matter herein contained will provoke discussion, and in order to promote this end extended expressions of opinion or attempted applications of theory to results have been avoided. A running commentary on the results of the tests, however, emphasizing matters of particular interest and indicating a few points that might lead to interesting analyses, is included in this report. When the results of the 52-week tests become available it is the intention to publish a thorough analysis of the entire series in another bulletin.

The purpose of this series of tests was to determine—

(1) The effect of age on the strength of concrete;

(2) The effect of variation in the consistency on the strength of concrete; and

(3) The effect of different types of aggregates on the strength of concrete.

The first question is perhaps the most important, since an early attainment of considerable strength and no subsequent decrease in

strength are two essential qualities in concrete, in order that a structure may be put to the use for which it is intended as soon as possible and that there shall be no subsequent deterioration in strength.

The least age at which any tests were made was four weeks, and at that period in no case except that of the cinder concrete, wet consistency, did the compressive strength fall below 2,000 pounds per square inch, while the cinder concrete had in every case a compressive strength of at least 1,000 pounds per square inch.

In every instance the compressive strength shows a substantial increase from four to thirteen weeks, with the single exception of limestone concrete mixed to a wet consistency, for which a decreased strength is indicated by the tests, a decrease which continues to the age of twenty-six weeks. This decrease in the strength of the limestone concrete is unexplainable, and the results of the 52-week tests on this material will be of value as indicating whether or not this decrease continues to the latter period. The other aggregates show either the same or a slightly greater strength at twenty-six weeks than at thirteen weeks.

The transverse tests on both the long and the short beams bear out very closely the fact indicated by the compression tests on the cylinders and cubes, and lead to the belief that the tensile and compressive strength are affected alike by both age and consistency. The effect on the strength of the variation in the consistency is clearly shown. In almost every case the concrete of the damp consistency is the strongest and that of the wet consistency the weakest. This is true for the three ages at which the concrete was tested, and is confirmed by the tests of the beams as well as of the cylinders and the cubes. Attention is called to the fact that the damp consistency used is much wetter than the damp consistency used in making mortar building blocks, for which the same conclusions may not apply.

The difference in strength of the stone and gravel concretes of the three consistencies is more pronounced than in the case of the cinder concrete. The effect of the consistency on the strength seems to depend to a great extent on the behavior of the concrete while being tamped and to the method used in tamping. Great care was taken to tamp all the concretes in the same manner. The thorough mixing of the concrete is absolutely essential and has a marked influence on the consistency.

The relatively slight influence exerted by the consistency on the strength of cinder concrete may be partly due to the structural weakness of the cinders themselves, which in the drier mixtures were to a great extent broken up by the tamper, while in the wet mixtures, the cinders would move from beneath the tamper.

While it is true that in almost every instance the drier mixtures give the greater strength, it does not follow that dry (or damp)

mixtures should be used in construction. Practical considerations warrant the use of a wet mixture. The difficulty in securing efficient tamping and a smooth finish in a damp concrete, the loss of strength due to the unavoidable drying out of the concrete used above water, the difficulty of securing in reinforced concrete an intimate union with the steel, and the far greater ease of placing wet concrete all seem to warrant the sacrifice of what in many cases is but a slight difference in strength for a greater ease of manipulation and a thorough bedding of the steel, which is of the utmost importance in reinforced concrete work.

It is dangerous to draw any general conclusions as to the relative value of concrete made of the four aggregates used unless the character of the aggregates used in this particular series of tests is carefully kept in mind. The gravel, granite, limestone, and cinders were used as available representative types of aggregates, and while the results indicate that the granite makes the strongest concrete, it should not be assumed, therefore, that a granite concrete is stronger than a gravel, limestone, or cinder concrete. Every material should be accepted or rejected on the results of the tests of its qualities, regardless of the tests of other materials of the same type. Apparently insignificant differences in two materials which appear to be similar often cause considerable difference in the strength of concrete made from them. For instance, two limestones from the same quarry crushed and screened under similar conditions—except that one was screened while wet, which caused the dust to adhere to the surface of the stone—would make concretes of considerable difference in strength.

Because the hard, flinty gravel used in these tests gave excellent results, it does not necessarily follow that a similar well-graded gravel, but composed of soft limestone or shale, would give like results. No series of investigations, however elaborate, will do away with the necessity of careful inspection of the materials to be used. The relative value of materials reported in this bulletin should be recognized, therefore, as applicable only to the particular materials from which the reported physical properties were obtained.

ACKNOWLEDGMENTS.

All the material used in the tests herein reported was donated by the following companies, who deserve credit for their interest and hearty cooperation in advancing the work:

Cement.—Iola Portland Cement Company, Iola, Kans.
Atlas Portland Cement Company, Hannibal, Mo.
Whitehall Portland Cement Company, Cementon, Pa.
Universal Portland Cement Company, Chicago, Ill.
Edison Portland Cement Company, New Village, N. J.
Omega Portland Cement Company, Mosherville, Mich.

Old Dominion Portland Cement Company, Fordwick, Va.
Lehigh Portland Cement Company, Mitchell, Ind.
St. Louis Portland Cement Company, St. Louis, Mo.

Sand.—Union Sand and Material Company, St. Louis, Mo. A recent river sand dredged from Meramec River at Drake, Mo.

Gravel.—Union Sand and Material Company, St. Louis, Mo. A recent river gravel dredged from Meramec River at Drake, Mo.

Granite.—Schneider Granite Company, St. Louis, Mo. A hard, red granite quarried near Graniteville, Mo.

Cinders.—United Railways Company, St. Louis, Mo. These cinders were obtained from the Dehodiamont power house, St. Louis, and gave better results than those selected from other sources.

Limestone.—Fruin-Bambrick Construction Company, St. Louis, Mo. Obtained from a quarry in St. Louis.

The tests were supervised by Louis H. Losse, and the results were computed and collated by Harry Kaplan.

TESTS OF CONSTITUENT MATERIALS.

CEMENT.

PREPARATION OF TYPICAL CEMENT.

The cement used in all the tests in these laboratories is known as typical Portland cement. It is prepared by thoroughly mixing together a number of Portland cements. The method of preparing the typical Portland cement that was used in the tests herein reported and in the tests on the second and third series, reinforced beams, including in all 576 beams, cylinders, and cubes, was as follows:

One thousand eight hundred sacks of cement, 200 from each of nine companies, were used. Two hundred sacks of one brand were spread over a concrete floor 25 by 40 feet in area and thoroughly mixed by hoeing from side to side. Two samples were then taken, a 50-pound sample for tests to be made by the constituent-materials section, and a smaller one for chemical tests. The cement was then resacked. When all the brands had been separately mixed in this way, two sacks of each brand were spread on the floor in a layer about 3 inches thick. One brand was spread upon another in blanket form, making nine separate layers of cement for the nine brands used. The mass was mixed very carefully with shovels until a uniform mixture was obtained. A 10-pound sample was taken for physical tests and the cement was sealed in air-tight cans, two cans of 800 pounds capacity each being required to hold one mix.

RESULTS OF TESTS.

Table 1 contains the results of the chemical tests of the individual brands, made on samples taken as indicated above. The average of the columns may be taken as the analysis of the typical Portland cement.

TABLE 1.—*Chemical analyses of individual brands used in the preparation of typical Portland cement.*

Cement No.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Water (H_2O).	Ignition loss.	Undetermined.
200	20.34	9.36	3.04	63.40	1.35	1.47	....	....	1.04
201	22.12	6.50	3.22	61.39	2.58	1.89	0.94	0.55	.97
202	20.96	8.08	2.80	62.68	1.45	1.54	.18	1.61	.70
203	20.52	8.54	2.68	62.47	1.92	1.50	.29	1.43	.65
204	20.04	7.70	2.74	63.26	2.24	1.56	.08	.96	1.60
205	22.04	9.50	1.42	61.46	1.68	1.58	.55	.84	.93
206	22.80	9.56	1.06	61.04	1.37	1.82	.64	.77	.94
207	22.96	9.34	1.32	61.20	1.47	1.81	.28	.86	.76
208	23.48	8.22	1.80	61.10	1.62	1.68	.44	.81	.85
Average	21.70	8.53	2.23	62.00	1.74	1.67	.43	.98	.94

Table 2 contains the results of the physical tests, except those for strength of the individual brands. All these tests were made according to the methods recommended by the special committee on uniform tests of cement of the American Society of Civil Engineers.

TABLE 2.—*Physical tests of individual brands used in typical Portland cement.*[a]

Cement No.	Residue on sieve (per cent)—		Specific gravity.	Water (per cent).	Time of set (minutes).				Normal pat tests.	
					Vicat.		Gilmore.			
	100.	200.			Initial.	Final.	Initial.	Final.	Air (70° F.).	Water (70° F.).
200	5.9	20.9	3.136	21.0	184	340	155	325	Normal	Normal.
201	5.5	22.1	3.058	20.5	93	378	110	486	do	Do.
202	7.8	24.6	3.121	20.5	138	329	152	393	do	Do.
203	4.4	20.6	3.099	21.5	117	315	150	352	Crack 1" long ¼" from edge.	Do.
204	2.0	12.0	3.087	24.0	124	416	229	458	Normal	Do.
205	6.0	22.2	3.165	21.0	127	370	178	394	Warped $\frac{1}{32}$" from edge.	Do.
206	5.3	21.5	3.127	21.0	113	338	195	441	Normal	Do.
207	6.0	23.2	3.129	20.5	146	391	182	372	do	Do.
208	3.1	21.6	3.141	22.5	170	332	217	400	do	Do.
Average	5.1	21.0	3.108	21.4	135	357	174	402		

[a] In the accelerated pat tests, in water at 212° F. for 3 hours and in steam maintained at normal pressure for 5 hours, the results were normal in each case for each brand of cement.

Table 3 contains the results of the strength tests of the individual brands. Tests were made for both neat cement and 1:3 mortar with Ottawa sand, in tension, compression on 2-inch cubes, and modulus of rupture on a 1 by 1 inch prism tested by a center load on a 12-inch span. All tests were made according to the methods recommended by the special committee on uniform tests of cement of the American Society of Civil Engineers.

TABLE 3.—*Strength tests of individual brands used in the preparation of typical Portland cement.*

Cement No.	Temperature (°F.). Air.	Water.	Closet	Tanks.	Water (per cent).	Strength of neat test pieces (pounds per square inch). Tensile. 1 day.	7 days.	28 days.	90 days.	180 days.	Compressive. 1 day.	7 days.	28 days.	90 days.	180 days.	Transverse. 1 day.	7 days.	28 days.	90 days.	180 days.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
200	64.4	68.0	64.4	53.6	21.0	332	655	864	859	886	2,375	10,090	11,130	12,918	17,820	702	1,962	2,088	2,070	2,070
						324	698	870	842	878	2,500	9,225	11,310	13,200	18,172	828	1,800	1,998	2,124	2,124
						332	672	852	846	859	2,400	10,925	10,060	13,270	16,542	792	1,980	2,124	2,196	2,232
Average						329	675	862	849	874	2,425	10,080	10,833	13,129	17,511	774	1,914	2,070	2,130	2,142
201	68.8	68.0	61.4	70.0	20.5	144	616	772	835	880	1,425	5,895	8,100	11,520	11,450	396	1,224	1,674	2,016	1,980
						172	601	729	886	861	1,400	5,638	8,655	12,225	11,038	414	1,260	1,548	1,980	1,944
						171	......	728	842	848	....	5,088	8,022	11,965	11,350	......	1,278	1,710	2,061	1,908
Average						162	608	743	854	863	1,413	5,540	8,259	11,903	11,279	405	1,254	1,644	2,019	1,944
202	64.4	68.0	64.4	68.9	20.5	401	754	792	842	832	3,900	7,500	9,250	12,272	13,825	702	1,692	1,764	1,962	1,926
						475	725	776	803	881	3,750	8,125	9,775	11,905	14,060	702	1,584	1,728	2,034	1,836
						487	760	780	832	870	4,025	....	9,300	12,050	14,187	648	1,728	1,836	1,935	1,980
Average						454	746	783	826	861	3,892	7,813	9,442	12,076	14,024	684	1,668	1,776	1,977	1,914
203	66.4	68.0	68.9	73.4	21.5	299	562	781	827	840	2,400	6,778	9,425	11,525	13,525	792	1,296	1,728	1,971	2,052
						312	585	814	886	835	1,625	7,300	8,867	11,312	14,028	774	1,260	1,908	1,908	1,980
						292	548	809	881	854	2,125	6,990	8,880	12,022	13,842	972	1,404	1,836	1,980	2,124
Average						301	565	801	865	843	2,050	7,023	9,057	11,620	13,798	846	1,320	1,824	1,953	2,052
204	68.0	68.0	66.2	71.6	24.0	276	622	715	790	835	2,325	6,675	9,200	11,457	14,025	558	1,368	1,710	1,926	2,088
						285	640	712	815	837	2,200	6,055	8,125	11,225	13,062	576	1,368	1,656	1,908	2,052
						275	623	732	821	826	2,225	6,195	8,475	....	13,705	558	1,296	1,602	1,890	2,016
Average						279	628	720	809	833	2,250	6,308	8,600	11,341	13,597	564	1,344	1,656	1,908	2,052
205	72.0	68.0	71.6	74.3	21.0	305	638	790	820	855	2,075	6,550	10,125	11,800	13,655	684	1,350	2,052	1,976	2,124
						308	616	762	811	862	1,975	7,050	9,675	12,155	13,972	720	1,476	2,120	1,926	1,980
						326	620	806	809	888	2,000	7,175	9,475	11,450	14,137	702	1,386	1,962	2,052	1,998
Average						313	625	786	813	868	2,017	6,925	9,758	11,802	13,921	702	1,404	2,045	1,985	2,034
206	70.0	68.0	71.6	69.8	21.0	452	576	758	809	770	3,500	6,625	9,370	11,465	14,377	882	1,584	1,494	1,710	2,088
						434	548	735	827	810	3,225	6,975	9,550	11,750	13,747	882	1,548	1,656	1,836	2,016
						438	578	742	851	775	3,400	7,300	9,655	11,505	13,712	936	1,602	1,557	1,809	2,124
Average						441	567	745	829	785	3,375	6,967	9,525	11,573	13,945	900	1,578	1,569	1,785	2,076

TABLE 3.—*Strength tests of individual brands used in the preparation of typical Portland cement*—Continued.

Cement No.	Temperature (F°.).				Water (per cent).	Strength of neat test pieces (pounds per square inch).														
						Tensile.					Compressive.					Transverse.				
	Air.	Water.	Closet.	Tanks.		1 day.	7 days.	28 days.	90 days.	180 days.	1 day.	7 days.	28 days.	90 days.	180 days.	1 day.	7 days.	28 days.	90 days.	180 days.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
207	73.0	64.4	69.8	66.2	20.5	375	685	827	798	820	3,550	8,425	9,698	14,037	13,817	990	1,530	1,926	1,800	1,962
						375	720	825	810	800	3,800	8,000	10,228	12,583	13,722	846	1,494	1,823	1,827	1,980
						358	692	788	793	804	3,700	8,300	10,275	13,325	14,200	972	1,494	1,962	1,728	1,998
Average						369	699	813	800	808	3,683	8,242	10,067	13,320	13,913	936	1,506	1,904	1,785	1,980
208	66.2	68.0	69.8	65.3	22.5	326	820	748	810	825	3,675	7,375	9,668	10,798	14,050	864	1,728	1,566	2,106	1,998
						355	792	762	807	828	3,350	7,975	9,000	11,347	13,797	954	1,512	1,620	1,980	2,052
						342	784	750	814	835	3,575	7,625	9,300			936	1,620	1,544	2,021	1,980
Average						341	799	753	810	829	3,533	7,658	9,323	11,070	13,923	918	1,620	1,577	2,036	2,010
Grand average					21.4	336	659	778	828	840	2,789	7,379	9,429	12,044	13,993	761	1,512	1,674	1,953	2,023

Cement No.	Temperature (°F.).				Water (per cent).	Strength of 1:3 standard-sand mortar test pieces (pounds per square inch).											
						Tensile.				Compressive.				Transverse.			
	Air.	Water.	Closet.	Tanks.		7 days.	28 days.	90 days.	180 days.	7 days.	28 days.	90 days.	180 days.	7 days.	28 days.	90 days.	180 days.
1	2	3	4	5	22	23	24	25	26	27	28	29	30	31	32	33	34
200	64.4	68.0	64.4	53.6	8.9	364	425	426	515	3,025	5,000	4,175	4,787	720	792	846	990
						375	419	461	510	2,475	4,575	4,300	5,363	630	810	936	972
						395	413	445	486	3,325	5,125	4,200	5,150			864	
Average						378	419	444	504	2,942	4,900	4,225	5,100	675	801	882	981
201	68.8	68.0	61.4	70.0	8.9	171	290	412	421	1,450	2,225	3,000	3,175	342	576	828	756
						156	330	410	454	1,475	2,225	3,050	3,300	378	576	819	810
						194	320	428	430	1,375	2,350	2,925	3,250	288	612	864	
Average						174	313	417	435	1,433	2,267	2,992	3,242	336	588	837	783
202	64.4	68.0	64.4	68.9	8.9	335	425	408	430	2,696	4,000	4,525	3,800	648	882	972	918
						320	457	439	478	2,472	4,375	4,425	3,925	684	954	932	972
						328	435	445	464	2,875	4,250	4,650	3,775				
Average						328	439	431	457	2,681	4,208	4,400	3,833	666	918	952	945

203	66.4	68.0	68.9	73.4	9.1	265	355	431	452	1,700	3,667	4,000	4,400	612	828	684	972
						272	411	446	445	1,775	3,875	4,225	4,225	540	774	738	918
						275	362	443	456	1,650	3,450	4,125	4,100	558	684	720	....
Average	....	....	....	....	....	271	376	440	451	1,708	3,664	4,117	4,242	570	762	714	945
204	68.0	68.0	66.2	71.6	9.5	363	420	495	475	2,100	3,550	3,900	4,325	540	810	936	1,008
						322	406	472	450	1,975	3,425	3,800	4,450	540	810	918	891
						330	394	466	460	2,150	3,725	3,500	4,225	540	....	....	....
Average	....	....	....	....	....	338	407	478	462	2,075	3,567	3,733	4,333	540	810	927	950
205	72.0	68.0	71.6	74.3	9.0	247	401	446	482	1,625	2,975	3,925	4,375	450	828	1,026	1,008
						219	424	430	465	1,775	2,750	3,850	4,500	504	918	972	972
						220	387	449	460	1,625	3,000	3,800	4,625	576	940	954	....
Average	....	....	....	....	....	229	404	442	469	1,675	2,908	3,858	4,500	510	895	984	990
206	70.0	68.0	71.6	69.8	9.0	284	406	450	465	2,100	3,625	3,325	4,450	738	873	972	756
						281	445	436	493	2,100	3,325	3,175	4,400	648	918	900	783
						272	....	493	468	2,075	3,425	3,125	4,625	720	837	914	774
Average	....	....	....	....	....	279	426	460	475	2,092	3,458	3,208	4,492	702	876	929	771
207	73.0	64.4	69.8	66.2	8.9	324	455	488	445	1,900	3,425	4,425	4,975	720	972	990	702
						330	418	476	438	2,100	3,550	4,400	4,900	666	999	936	720
						358	464	452	450	2,250	3,650	4,275	4,950	666	1,026	936	720
Average	....	....	....	....	....	337	446	472	444	2,083	3,542	4,367	4,942	684	999	954	714
208	66.2	68.0	69.8	65.3	9.3	327	427	535	496	2,225	3,750	4,162	4,225	720	1,539	1,008	684
						330	472	509	521	2,350	3,500	4,750	4,575	738	1,566	985	702
						291	462	530	526	2,200	3,650	....	4,400	666	1,566	1,026	756
Average	....	....	....	....	....	316	454	525	514	2,258	3,633	4,460	4,400	708	1,557	1,006	714
Grand average	....	....	....	....	9.1	294	409	457	468	2,105	3,572	3,905	4,343	593	920	907	847

TABLE 4.—*Physical properties of cements used in concrete beams.*

Register No.	Specific gravity.	Temperature (°F.).		Water (per cent).	Time of set (minutes).				Residue on sieve (per cent)—		Tensile strength of neat cement (pounds per square inch).					Soundness (as indicated by appearance of pat).
		Water.	Air.		Vicat.		Gilmore.		100.	200	1 day.	7 days.	28 days.	90 days.	180 days.	
					Initial.	Final.	Initial.	Final.								
209	3.112	75.2	71.6	21.0	138	370	180	403	4.8	19.8	422	696	841	704	836	Pat A, warped $\frac{1}{64}$ inch around edge.
210	3.116	75.2	71.6	21.0	137	372	239	429	4.6	20.8	468	698	816	714	836	Normal.
211	3.111	75.2	71.6	21.0	132	386	226	401	5.0	22.4	496	678	828	757	843	Pat D, warped $\frac{1}{64}$ inch around edge.
213	3.111	74.0	70.6	21.0	180	389	275	430	5.2	20.8	451	687	799	792	857	Pat C, warped $\frac{1}{64}$ inch around edge.
214	3.116	74.0	70.6	21.0	195	379	262	410	5.0	21.8	470	758	848	769	851	Normal.
218	3.108	75.0	71.6	21.0	200	443	192	475	4.9	21.3	373	770	769	812	829	Do.
219	3.113	75.0	71.6	21.0	195	432	275	470	4.8	20.7	371	793	785	798	822	Do.
220	3.112	77.0	65.0	21.0	222	446	279	512	5.0	20.8	382	757	765	795	833	Do.
223	3.113	73.0	68.0	21.0	174	435	245	472	4.6	21.2	368	723	791	801	821	Do.
224	3.114	73.0	68.0	21.0	192	415	250	474	4.7	21.1	425	760	758	816	840	Do.
225	3.118	73.0	68.0	21.0	182	419	242	466	5.4	21.0	451	735	782	790	836	Do.
226	3.113	73.0	68.0	21.0	171	411	231	457	5.1	20.8	424	749	791	816	823	Do.
227	3.113	70.0	68.5	21.0	203	438	271	478	4.8	20.7	372	722	821	816	883	Do.
229	3.111	70.0	68.5	21.0	180	424	244	468	5.0	21.2	409	809	827	831	849	Do.
230	3.113	67.1	72.5	21.0	195	443	223	485	4.0	21.4	427	769	881	841	794	Do.
231	3.115	67.1	72.5	21.0	206	443	243	472	4.9	21.4	389	731	871	835	839	Do.
232	3.109	67.1	72.5	21.0	194	458	235	460	5.0	21.6	441	768	890	829	838	Do.
233	3.112	68.0	55.4	21.0	200	498	265	505	5.2	21.5	290	648	857	846	870	Do.
335	3.114	68.0	55.4	21.0	233	470	282	484	4.6	20.7	316	645	858	839	842	Do.
336	3.113	64.4	48.2	21.0	262	472	268	487	4.5	20.5	220	675	886	857	911	Do.
237	3.115	64.4	48.2	21.0	263	454	250	357	4.5	20.5	221	648	877	846	887	Do.
271	3.115	68.0	50.0	21.0	300	500	357	532	4.7	21.1	309	742	826	823	876	Do.
272	3.118	68.0	59.0	21.0	238	381	255	465	4.8	21.4	433	729	841	855	864	Pat A, 2-inch shrinkage crack $\frac{1}{4}$ inch from edge.
274	3.111	68.0	59.0	21.0	219	432	353	451	4.8	21.2	420	739	829	839	877	Pat A, $\frac{1}{2}$-inch shrinkage crack $\frac{1}{4}$ inch from edge.
275	3.116	68.0	68.0	21.0	170	416	143	403	4.8	21.4	387	786	791	790	859	Pat A, $1\frac{1}{2}$-inch shrinkage crack $\frac{1}{4}$ inch from edge.
283	3.111	68.0	70.0	21.0	147	419	175	404	4.9	21.1	404	717	805	840	851	Normal.
289	3.114	68.0	70.0	21.0	138	240	239	444	5.0	21.1	421	725	760	830	874	Do.
291	3.113	68.0	75.0	21.0	153	377	184	405	4.9	21.0	431	761	774	816	856	Pat A, warped $\frac{1}{64}$ inch around edge.
292	3.114	68.0	75.2	21.0	139	369	189	405	4.9	21.1	436	777	758	814	860	Normal.
293	3.112	68.0	75.2	21.0	152	364	259	456	4.7	20.7	425	768	765	819	871	Do.
301	3.112	68.0	74.5	21.0	134	450	297	486	4.9	21.5	427	799	798	829	867	Do.
302	3.110	68.0	74.5	21.0	190	466	318	517	4.8	21.3	433	760	803	821	868	Do.
303	3.110	68.0	59.9	21.0	208	447	290	508	5.0	21.6	428	759	796	835	870	Do.
304	3.113	68.0	59.9	21.0	225	464	320	524	4.7	21.4	422	732	783	828	870	Do.
309	3.111	68.0	70.7	21.0	156	388	227	461	4.8	21.5	403	733	727	818	868	Do.
312	3.110	68.0	62.6	21.0	176	425	215	468	4.8	21.6	386	729	823	838	843	Do.

313	3.112	68.0	62.6	21.0	182	437	206	474	5.1	21.7	376	733	795	844	852	Do.
314	3.112	68.0	62.6	21.0	154	448	252	482	5.1	21.7	356	715	807	839	832	Do.
316	3.116	68.0	66.0	21.0	135	425	174	443	4.8	21.5	408	707	812	823	823	Do.
317	3.114	68.0	66.0	21.0	127	416	188	440	4.9	21.5	416	705	811	847	822	Do.
318	3.118	68.0	66.0	21.0	133	404	194	443	5.2	21.2	420	706	807	824	834	Do.
Average	3.113	69.7	66.5	21.0	184	421	244	459	4.9	21.2	398	733	811	816	851	

Table 4 contains the results of all the physical tests made of the typical Portland cement that was used in the present series of concrete beams. In the column "Register No." is given the register number of the cement used. Each number corresponds to two cans of 800 pounds each of typical Portland cement. The sample for each test was taken as already indicated.

As these tests were made with the sole idea of checking the uniformity with which the typical Portland cement was prepared, a full series of neat and sand tests was thought unnecessary and undesirable, for it would entail too much routine work on the part of the constituent-materials laboratory. Accordingly, only tension tests on neat cement were made.

SAND.

The same sand was used with all the aggregates tested. It is known as Meramec River sand, and is composed of flint grains having comparatively smooth surfaces. The yellowish-brown color of the flint imparts a tint of the same color to the sand as a whole.

Tables 5 and 6 (p. 17) give the results of the physical tests on this material. The granulometric analysis in Table 6 shows the sand to be rather finer than desirable. The percentage of voids was computed from the weight per cubic foot and the specific gravity.

Table 7 (p. 18), which contains the results of the tests made on the cement used in the preparation of the test pieces reported in Table 5, will aid in the interpretation of the values given in the latter table.

TABLE 5.—*Tests of mortar made with Meramec River sand (Sd. 43) and typical Portland cement (Ct. 140) in concrete beams.*

Fineness of sand.	Proportion of mortar.	Water (per cent).	Temperature (°F.).		Tensile strength (pounds per square inch).					Compressive strength (pounds per square inch).					Transverse strength (pounds per square inch).				
			Air.	Water.	7 days.	28 days.	90 days.	180 days.	360 days.	7 days.	28 days.	90 days.	180 days.	360 days.	7 days.	28 days.	90 days.	180 days.	360 days.
Passed ¼-inch screen.	1:3	11.5	71.0	68.0	274	438	418	443	480	2,375	4,075	5,625	5,125	5,172	594	882	1,044	972	1,080
					263	422	415	467	473	2,250	4,175	5,425	4,900	5,200	576	936	1,008	1,080	1,098
					260	416	446	487	486	2,325	4,050	5,650	4,850	5,210	594	846	1,026	972	1,062
	Average				266	425	426	466	480	2,317	4,100	5,567	4,958	5,194	588	888	1,026	1,008	1,080
	1:4	11.0	71.0	68.0	180	302	352	391	401	1,375	2,450	3,625	3,600	3,715	396	612	810	846	864
					186	294	352	355	408	1,375	2,350	3,900	3,675	3,775	396	666	864	846	900
					190	306	361	373	416	1,325	2,375	3,812	3,550	3,740	378	630	882	900	846
	Average				185	301	355	373	408	1,358	2,392	3,780	3,608	3,743	390	636	852	864	870
Size, 30–40	1:3	11.5	65.0	68.0	215	293	343	359	360	1,425	2,750	3,400	3,550	3,600	396	630	882	774	828
					224	294	350	353	372	1,400	2,700	3,450	3,500	3,618	414	648	954	810	900
					207	299	344	335	368	1,425	2,650	3,375	3,675	3,642	432	612	864	882	792
	Average				215	295	346	349	367	1,417	2,700	3,408	3,575	3,630	414	630	900	822	840

TABLE 6.—*Physical properties of sand and other materials forming aggregates used in concrete beams.*

Kind of material.	Specific gravity.	Percentage of voids (computed).	Weight (pounds per cubic foot).	Percentage passing sieve or screen—												
				200.	100.	80.	50.	40.	30.	20.	10.	¼-inch.	½-inch.	¾-inch.	1-inch.	1¼-inch.
Cinders	1.530	50.7	47.0	2.84	4.17	4.91	6.45	8.26	10.48	13.66	21.07	36.89	60.32	81.44	89.68	100
Granite	2.585	40.9	95.3	1.59	2.29	2.62	3.22	3.74	4.38	5.45	8.50	19.88	57.54	99.25	99.71	100
Gravel	2.450	33.0	102.4	0	0	0	0	0	0	0	.95	43.0	79.3	95.2	98.5	100
Limestone	2.489	37.1	97.7	2.96	3.48	3.70	4.18	4.68	5.23	6.21	10.69	28.71	60.86	96.04	99.37	100
Meramec River sand	2.597	37.9	100.6	.20	1.30	3.60	13.90	37.00	64.00	81.50	97.00	100	....	....	....	....

AGGREGATE.

The results of the physical tests on the granite, gravel, cinders, and limestone used in the plain beams are reported in Table 6. The crushing strength of the 1:2:4 concrete made of these aggregates is given in connection with the results of tests on the plain beams, in Table 10 (pp. 48–53).

Table 7.—*Tests of cement 140, used in testing Meramec River sand (strength in pounds per square inch).*

Kind of test.	Neat.						1:3 mortar.				
	1 day.	7 days.	28 days.	90 days.	180 days.	360 days.	7 days.	28 days.	90 days.	180 days.	360 days.
Tension	362	710	696	775	827	846	342	527	445	405	414
	375	700	705	792	811	853	375	540	445	388	408
	372	718	709	781	813	831	364	531	413	394	405
Average	370	709	703	783	817	843	360	533	434	396	408
Compression	3,425	9,300	10,512	12,288	13,980	14,274	1,570	3,200	......	5,025	5,500
	3,275	9,325	11,125	12,612	13,725	14,410	1,555	3,300	3,698	5,025	5,425
	3,300	9,175	10,497	12,862	13,803	14,320	1,735	3,025	3,400	4,800	5,239
Average	3,333	9,266	10,711	12,590	13,836	13,335	1,620	3,175	3,549	4,950	5,388
Transverse	756	1,440	1,872	1,998	1,944	2,142	......	......	......	......	......
	792	1,440	1,908	2,016	2,088	2,232	......	......	......	......	......
	774	1,476	1,944	1,962	2,034	2,124	......	......	......	......	......
Average	774	1,452	1,908	1,992	2,022	2,166	......	......	......	......	......

Remarks.—Fineness: Residue on No. 100 sieve, 6.8 per cent; on No. 200 sieve, 22.8 per cent. Specific gravity, 3.12. Time of set: Initial, 142 minutes; final, 428 minutes. Soundness: Pat test in air at 70° F., normal; in water at 70° F., normal; in water at 212° F., 3 hours, normal; in steam at normal pressure, 5 hours, normal. Water used in mixing: Neat, 20.5 per cent; mortar, 8.9 per cent. Temperatures: Of air, 71.0° F.; of water, 68.0° F.

PREPARATION OF TEST PIECES.

METHODS OF PROPORTIONING.

A 1:2:4 volume proportion was adopted for all the concrete used in the following tests. Since, however, the volume of a given weight of dry sand is greatly affected by the percentage of moisture present, it was thought best to do the actual proportioning by weight. The weight of 1 cubic foot of cement was assumed to be 100 pounds. The weight per cubic foot of the dry, loose sand and the dry, loose aggregate as determined by tests in the constituent-materials laboratory, was used in reducing the proportions by volume to the proportions by weight.

With this as a basis, the necessary weight of dry material for the desired batch was determined. Since the sand and stone, as stored in the bins, contained an appreciable amount of moisture, the dry weight of the material had to be increased by the weight of the moisture present before the batch could be weighed out. The percentage of moisture was determined on a 500-gram sample of the sand and stone each day on which beams were molded.

The above method of correcting for moisture was followed in the series of concrete beams and in the greater part of the first reinforced beam series. It was noticed from time to time, however, that the concrete when dumped from the mixer was not always of the same consistency, in spite of the fact that the total weight of water present (weight of water added plus the weight of the moisture in the sand and the stone) was a constant. A moisture determination was then made on a sample representing as nearly an average of the material in the bin as it was possible to obtain, and this was then maintained constant and gave much better results. The effect on the consistency of a given change in the weight of the moisture in the sand or stone does not appear to be the same as that of an identical change in the weight of the water added to the batch, the difference probably being due to the fact that the moisture test is only local and does not represent the true average of the material in the bin.

It should be noted here that the proportions by volume of the cinder concrete are nearer 1:2:5 than 1:2:4. This is due to an error in making the moisture determination at the time the weight per cubic foot was determined. The weight per cubic foot of the cinders, including apparently 11.1 per cent moisture, was reported as 68.1 pounds. Using these figures gives 61.3 pounds per cubic foot for the weight of the dry, loose cinders. These determinations were accepted as correct until a sample, which had been forgotten in the oven, showed 23 per cent moisture present. This error in the weight per cubic foot, due to insufficient drying of the test sample, was not discovered until the series of cinder beams was almost completed. While a new determination of the weight per cubic foot was made and the proportions by weight and volume modified accordingly, it was thought best to use these proportions and the correct weight per cubic foot on the remaining cinder beams rather than the 1:2:4 volume proportions, in order to make the cinder beams comparable among themselves even if not strictly comparable with the beams of other aggregates.

The weight per cubic foot, as redetermined, was found to be 47.0 pounds.

METHOD OF MIXING AND CONSISTENCY.

MIXING.

All concrete was mixed in a motor-driven cubic-yard cube mixer, which is equipped with a charging hopper. All water used in mixing concrete was weighed and was supplied to the mixer through a hose attached to a water barrel, which is mounted on a platform scale on a support above the mixer. To insure uniform conditions the interior of the mixer was wetted down each morning before the first mix of the day. All concrete was mixed two minutes dry and three minutes

wet, after which it was dumped on the cement floor, shoveled into wheelbarrows and wheeled to the molding floor. Sufficient material was charged into the mixer to make two beams, two cylinders, and two cubes from the same batch of concrete.

CONSISTENCY.

Definition.—The three consistencies, wet, medium, and damp, as here used, represent each a certain characteristic behavior and appearance of the concrete in the mixer, on the floor, and in the mold when subjected to tamping. In order to eliminate the personal equation as far as possible, the amount of water required to bring the batch to a desired consistency for a particular aggregate was carefully determined by trial before the test pieces were molded. Thereafter the weight of water to be used with each aggregate for that consistency could be obtained by making a simple correction each day, depending upon the percentage of water contained in the aggregate as it came from the bins. The total amount of water, including moisture, was expressed as a percentage of the total weight of the dry material and was maintained constant.

A brief description of the consistencies is given. It should be recognized that the consistencies as defined are purely arbitrary, but each, it is thought, represents a characteristic appearance and behavior, and, with a little practice, is readily distinguished from the others.

Wet consistency.—Concrete of wet consistency has a smooth and somewhat viscous appearance in the mixer, or immediately before dumping. It flows back from the ascending side of the mixer without any tendency toward "breaking" over at the top. The upper surface of the concrete in the bottom of the mixer rolls underneath the mass smoothly and is carried upward by adhesion to the metal. When dumped, it stands on the floor in a low pile, having a smooth surface, and showing neither voids nor individual stones. It can not be compacted by tamping in the molds, but splashes under the action of the tamper. When finished, water stands from one-fourth to one-half inch deep over the surface of the mold.

Medium consistency.—Concrete of medium consistency has a smooth appearance in the mixer, but shows a tendency to lump. As compared to that of wet consistency it flows less smoothly and is carried higher by the ascending side of the mixer, part flowing back smoothly and part breaking over at the top in lumps. When dumped, it stands in a higher pile with steeper side slopes, exhibiting a somewhat lumpy appearance, and showing individual stones, but no voids. The stones show an even coating of sand mortar. No water collects on the surface of the beam in the mold. The surface is easily finished with a trowel.

Damp consistency.—Concrete of damp consistency is decidedly granular in the mixer with little tendency to lump. The material is carried to the top of the mixer and falls in individual stones and fragments of mortar. When dumped, it stands at the same angle as medium concrete, showing both individual stones and voids. The surface of the pile is irregular. In the mold it offers considerable resistance to tamping, but compacts fairly well under hand tamping. No water flushes to the surface and it can not be finished smooth by troweling.

METHOD OF MOLDING.

BEAMS.

The beam molds consisted of three long steel channels with flanges turned outward, forming the sides and bottom of the mold. The ends were closed by short pieces of channels. The side and end pieces were removable. The molds were oiled before the concrete was placed, to prevent adhesion to the surface of the steel. In molding the plain beams the concrete was deposited in three layers of about equal thickness. The tamping was done by hand with a $13\frac{3}{4}$-pound tamper having a rectangular head $1\frac{1}{4}$ by $3\frac{1}{2}$ inches. The tamping was started at one side of one end of the mold and the tamper moved toward the opposite side, the width of the tamper at each stroke. The tamper was then set forward and the process repeated. In this way each part of the layer was tamped once. The mold was gone over twice in this way, after which the concrete was spaded back from the sides of the mold and the layer tamped a third time. The same operation was followed for each of the three layers. The surface of each beam was finished as smooth as possible by troweling.

The side and end pieces of the mold were removed at the end of twenty-four hours, and the beam was covered with burlap and allowed to remain on the bottom channel until moved into the moist room.

CYLINDERS AND CUBES.

In order to make the compression test representative of the true crushing strength of the concrete in the beam, the cylinders and cubes were molded from the same batch as the beam of the same number. They were molded in cast-iron separable molds, which were oiled previous to placing the concrete. The concrete was deposited in layers approximately 3 inches thick, and each layer was tamped twice, a circular hand tamper $3\frac{1}{2}$ inches in diameter and weighing 7 pounds being used for the cylinders and a rectangular tamper $3\frac{1}{2}$ by $1\frac{1}{4}$ inches, weighing $13\frac{3}{4}$ pounds, for the cubes.

In molding the cubes an effort was made to "spade" back the concrete from the sides of the mold, as was done in molding the beams.

The top surfaces of the cubes and cylinders were finished smooth with a trowel. All molds were removed at the end of twenty-four hours, and the test pieces were marked and transferred to the moist room.

MOVING AND STORAGE.

The large number of beams to be molded and the small space available made it imperative that the beams be moved as soon as possible. In no case could they remain where molded for more than 12 or 16 days. Since a concrete beam without reinforcement, and weighing about 1,200 pounds, has very little tensile resistance at this age, it was very important that they be handled at points that would prevent any chance of injury when being moved to the moist room. The following plan was followed, and was entirely satisfactory:

The channel forming the bottom of the mold was placed with the flanges turned down. At the points where the beams were supported in moving them, the webs of the bottom channels were cut away for a width of $1\frac{9}{16}$ inches. Prior to molding this slot was closed by a filler resting on the uncut flanges. When the beam was to be moved, this filler was driven out and a slightly narrower piece, which projected $1\frac{1}{4}$ inches beyond each side of the beam, was substituted.

A stirrup hanging from the chain blocks suspended from trolleys running on overhead **I** beams, was hooked under these projecting ends and lifted a 13-foot beam at two points 8 feet apart, which give equal positive and negative bending moment, and consequently minimum stresses in a beam of that length.

The beams in the moist room were stored six high, being supported at the same points as when brought to the damp closet.

All test pieces were sprinkled from a hose three times each day—at midnight, at 8 a. m., and at 4 p. m.—both before and after being placed in the moist room.

The temperature on the molding floor and in the moist room was recorded on a self-recording thermometer, and was maintained as near 70° as possible.

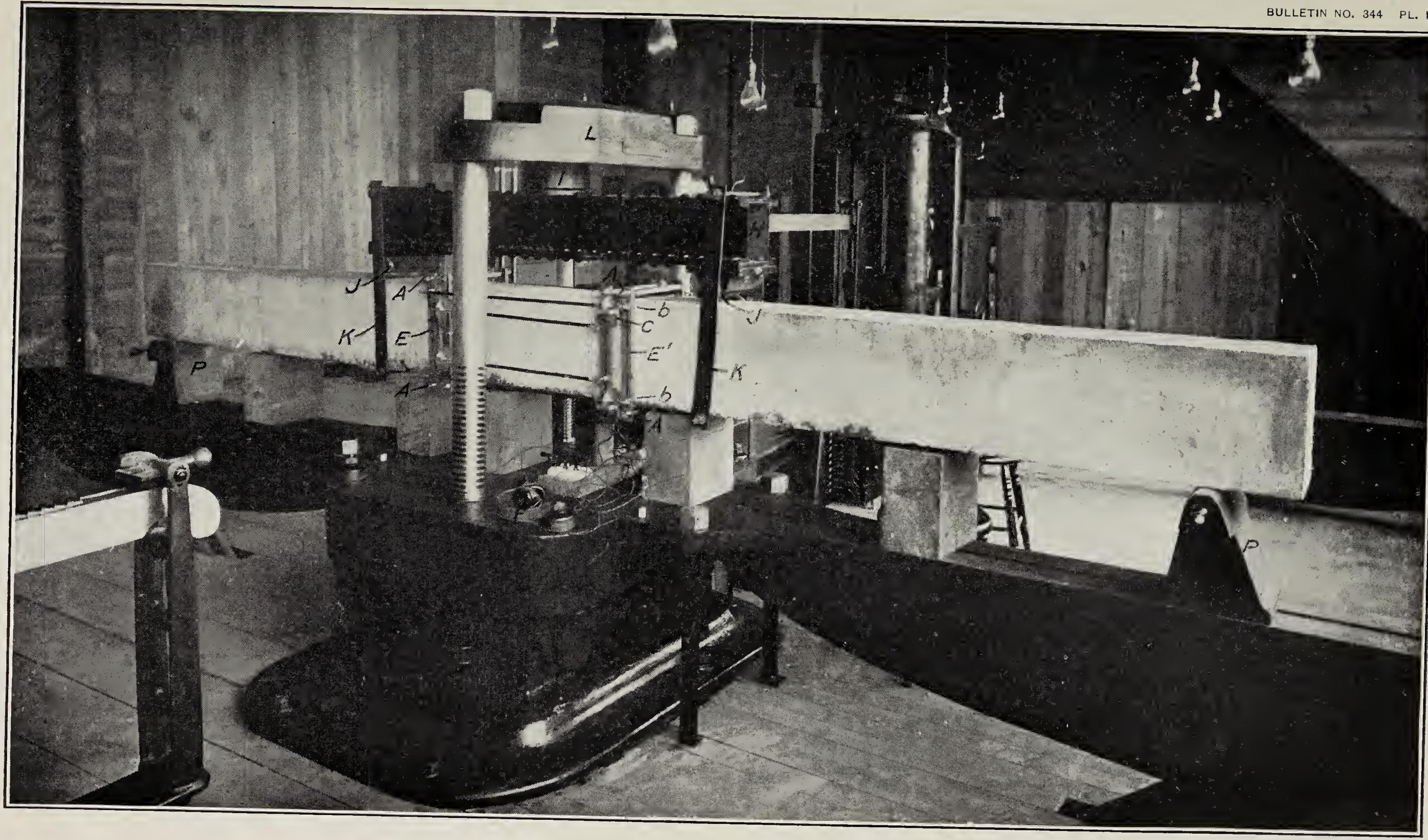
METHODS OF TESTING.

BEAMS.

LONG BEAMS.

APPARATUS.

Pl. I shows a photograph of a beam in place. The supports "P" for the beams have cylindrical top surfaces, and are so designed as to give a slight yielding motion outward, the object being to prevent any restraint of the beam which might follow from the lengthening of the lower fiber.



CONCRETE BEAM IN MACHINE READY FOR TESTING.

The deformeter yokes (E, E′) are fastened to the beam by tightening the nuts A, which force the contact points (b) and those directly opposite on the far side of the beam, against the surface of the concrete. The yokes are equidistant from the center of the beam, the contact points being 29.25 inches apart for the outer yokes and 24 inches apart for the inner set. The contact points of the outer set were 10 inches apart vertically and those of the inner yokes 5.75 inches apart. Both yokes were centered on the horizontal axis of the beam, thus bringing the contact points of the outer yokes 0.5 inch below the top and 0.5 inch above the bottom. The inner yokes were used only on some of the earlier beams in order to test the conservation of plane section. Four pins directly in line with the contact points on E engage cylindrical holes in the ends of the four rods, the other ends of which rest lightly on hard rubber rollers fastened to the arms C, which are rigidly connected to the yoke E.

Four micrometer screws reading directly to 0.0001 inch work in bushings fastened to the yoke E′. When any micrometer screw is brought in contact with the end of the corresponding rod, an electric contact is made, which causes a click in the telephone receiver F. Both yokes are divided into two vertical halves by rubber insulation, thus making it possible to read micrometers on both sides of the beam simultaneously.

METHOD OF ZERO DEFORMATIONS.

The deformation of concrete in compression in a beam is obtained from a reading of the upper micrometers, while the lower ones give the elongation of concrete. The readings of both upper and lower micrometers, making the usual assumption of conservation of plane section, fix the position of the neutral axis. The beams were all tested on a 12-foot span by two equal loads, applied at the third points of the span.

The load apparatus consists of a box girder (H) built of two 6-inch channels with a ½-inch cover plate on the top and the bottom. The load is transmitted from the testing machine to the box girder through a spherical bearing block (I), and from the box girder to the beam by two 2-inch steel rollers (J) bearing on two steel blocks (not shown) set in plaster of Paris. The upper surface of these blocks is a cylinder of very large radius whose axis is parallel to the length of the beam. With the exception of these bearing blocks the entire load apparatus is suspended from the top head (L) of the testing machine by a bolt passing through the spherical bearing block and engaging a plate on the inner surface of the box girder. The steel rollers (J) are kept in place by the casting which extends a trifle below their axis.

On commencing a test the bearing blocks are removed and yokes (K) are passed under the test beam and over the box girder directly above the 2-inch rollers. The head (L) is then run up until the reaction at the ends of the test beam has been so reduced that the total positive bending moment area is equal to the total negative bending moment area within the gage length, considering the beam as a continuous girder over four supports, viz, the two end supports and the two intermediate yokes.

This method is used for the following reason: In tests of beams as usually made, the upper and lower fibers of the beam are already deformed and are under stress due to the weight of the beam when the first, or zero, reading of the deformeters is taken; the deformations computed from these readings are too small by an amount which becomes relatively more and more important as the breaking loads decrease and which in the case of plain beams (many of which fail by a load but little in excess of the weight of the beam) becomes a very large part of the ultimate deformation.

When a beam rests freely on supports, the upper and lower fibers are deformed on account of the bending moment due to the weight of the beam. When the supports are at the ends of the beam the upper fibers are shortened and the lower are lengthened. For equal moduli of elasticity in tension and compression, which are constant for concrete under small loads, the deformation at any point of the beam is proportional to the area of the bending-moment diagram over that length. Therefore, when the total positive bending moment area in the gage length of the deformeters equals the total negative bending moment area in the gage length, the net total deformation in that length is zero, and both the upper and lower fibers of the beam have the same length as when unstressed. For a particular reaction at the ends of the beam the positive bending moment area in the gage length is equal to the negative bending moment area. In order to get this reaction the beams are supported at the third points by the head of the machine as previously described. As the stirrups under the third points of the span take more and more of the weight of the beam the end reactions become smaller and smaller and the character of the bending-moment diagram within the gage length changes until the desired condition is reached.

The method of finding the required reactions for total zero deformations within the gage length, in terms of the weight of the beam and other known quantities, may be understood by reference to fig. 1, as follows:

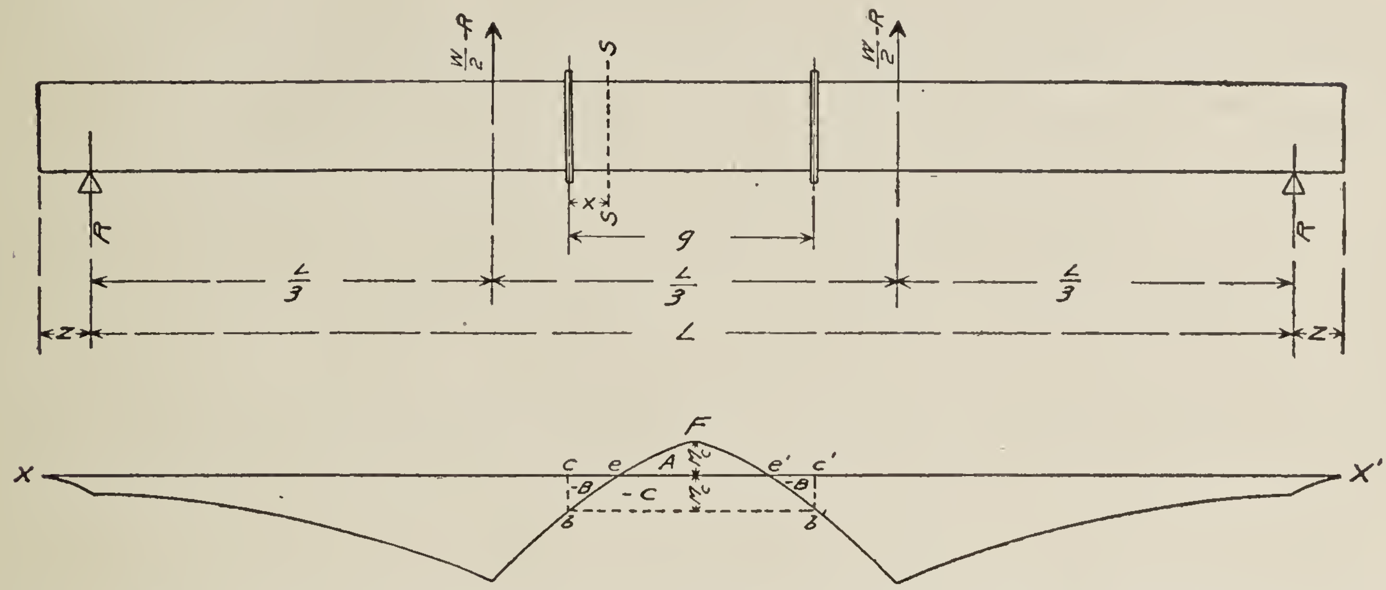


FIG. 1.—Diagrams illustrating method for computation of concrete beams. Upper diagram: Notation used. Lower diagram: Curve of bending moment within gage length (beam supported at third points).

Let L = distance between the supports.

g = gage length of deformeters.

Z = overhang of beam at each end.

$\frac{L}{3}$ = distance from each support to force exerted by each stirrup.

W = total weight of beam.

$\frac{W}{2}-R$ = force exerted by each stirrup at a distance of $\frac{L}{3}$ from the supports.

R = each reaction at end.

SS = any vertical section within the gage length at a distance, x, from one of the gage points.

M_x = bending moment at section SS.

M_o = bending moment at deformeters, where $x=0$.

M_c = bending moment at center of beam, where $x=\frac{g}{2}$.

m = constant bending moment over the gage length due to the weight of all attachments, such as bearing blocks under the load points and the deformeters. This weight is applied outside of the gage length and equally on each side of the center of the beam.

The bending moment at section SS, considering forces to the left only, is as follows:

$$M_x=R\left(\frac{L}{2}-\frac{g}{2}+x\right)+\left(\frac{W}{2}-R\right)\left(\frac{L}{6}-\frac{g}{2}+x\right)-\frac{W}{2(L+2Z)}\cdot\left(\frac{L}{2}+Z-\frac{g}{2}+x\right)^2+m.$$

Reducing to a simpler form gives:

$$M_x = \frac{RL}{3} - \frac{W}{4}\left(\frac{L}{6}+Z\right) - \frac{W}{4\left(\frac{L}{2}+Z\right)}\left(\frac{g}{2}-x\right)^2 + m.$$

The bending moment at the end of the gage length (x = 0) is as follows:

$$M_o = \frac{RL}{3} - \frac{W}{4}\left(\frac{L}{6}+Z\right) - \frac{Wg^2}{16\left(\frac{L}{2}+Z\right)} + m.$$

The bending moment at the center of the gage length $\left(x=\frac{g}{2}\right)$ is as follows:

$$M_c = \frac{RL}{3} - \frac{W}{4}\left(\frac{L}{6}+Z\right) + m.$$

The moment diagram between the third points, when there is both positive and negative bending moment in the gage length, is shown in fig. 1, in which xx′ is the horizontal axis of the moment diagram. The curve bee′b′ is a parabola and crosses the axis at two points (viz, e and e′) between the ends of the deformeters. Then in the gage length cc′ there is negative bending moment from c to e and from e′ to c′, and positive bending moment from e to e′. The dotted lines cb, c′b′, and bb′ are drawn for the purpose of demonstration. Then the distance M_c represents the bending moment at the center of the gage length, and M_o represents the bending moment at the end of the gage length. The negative bending-moment areas within the gage length are cbe and c′b′e′, each being represented by −B. The positive bending moment area within the gage length is eFe′ and is represented by A.

The condition that the positive bending moment area is equal to the negative bending moment areas is represented by the equation A = −2B. Adding the quantity −C to both sides of the equation gives A + (−C) = −2B − C. The first part of this equation is the area included between the horizontal line bb′ and the parabola bFb′; that is, $A + (-C) = \frac{2}{3}g\,[M_c + (-M_o)]$.

The second part of the equation is equal to the area of the rectangle bcc′b′; that is, $-2B - C = -gM_o$.

Therefore $\frac{2}{3}g\,[M_c + (-M_o)] = -gM_o$. Whence $2M_c = -M_o$.

Substituting the values of M_o and M_c as found above gives:

$$\frac{2RL}{3}-\frac{W}{2}\left(\frac{L}{6}+Z\right)+2m=-\frac{RL}{3}+\frac{W}{4}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16\left(\frac{L}{2}+Z\right)}-m.$$

$$\text{Whence } RL=\frac{3W}{4}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16\left(\frac{L}{2}+Z\right)}-3m$$

$$\text{and } R=\frac{3W}{4L}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16L\left(\frac{L}{2}+Z\right)}-\frac{3m}{L}.$$

In almost all the beams tested at the laboratories L, Z, g, and m are constant. It only remains to find W and to compute R. A table computed by the above formula has been compiled for all the usual values of W, from which the corresponding value of R in any case can be directly read.

METHOD OF TESTING.

When the test is commenced, the top head is run up until the reactions causing equal positive and negative bending moments over the gage length are developed at the ends of the beam. The sum of these reactions will appear on the weighing beam, the testing machine having been balanced before the weight of the beam and all test apparatus comes on it. A full set of deformeter readings is then taken.

After the readings at zero total deformations in the gage length and when the beam rests under its own weight are taken, the load is applied in increments of 200 to 1,000 pounds, depending on the stiffness of the beam, the top and bottom set of micrometer readings being recorded on the log sheets. Wood blocks are placed underneath the beam during the test, so that the distance it falls at rupture is not more than one-fourth inch.

SHORT BEAMS.

The longer portion of each beam after first failure is again tested on as great a span as its length permits, thus making a secondary series of short beams.

The load is applied by the same apparatus as that used for the long beams, but instead of being applied at the third points it is applied at points 2 feet from the center of the span. The short beams are not suspended for zero deformation readings, since for such small spans the deformation of the beam under its own weight is very small. On all short beams the outer yokes having a gage length of 29.25 inches are alone used.

CYLINDERS AND CUBES.

The cylinders and cubes are tested on a four-screw, 200,000-pound Olsen machine. To insure an even distribution of load over the entire cross section the ends of the cylinders are bedded in plaster of Paris to a thickness of about one-half inch on a piece of plate glass (previously oiled to prevent adhesion of the plaster). The bearing surfaces are made normal to the axis of the cylinder by means of a spirit level applied to its sides. The cubes are not capped with plaster of Paris, but a thin piece of asbestos is placed on a spherical bearing plate when under test, in order to take up all nonparallelism of the ends.

The load is in each case carried to failure, being applied continuously to rupture in the case of the cubes and in increments of 5,000 pounds, or approximately 100 pounds per square inch for the cylinders. For each increment gross deformations are read on two opposite sides of the cylinder over a gage length of 12 inches.

RESULTS OF TESTS.

BEAMS OF CONSTANT SPAN.

The detailed results of the tests of concrete beams 8 by 11 inches in section, 13 feet long, tested on a 12-foot span by two equal loads applied at the third points are given in Table 8 (p. 36), comprising the

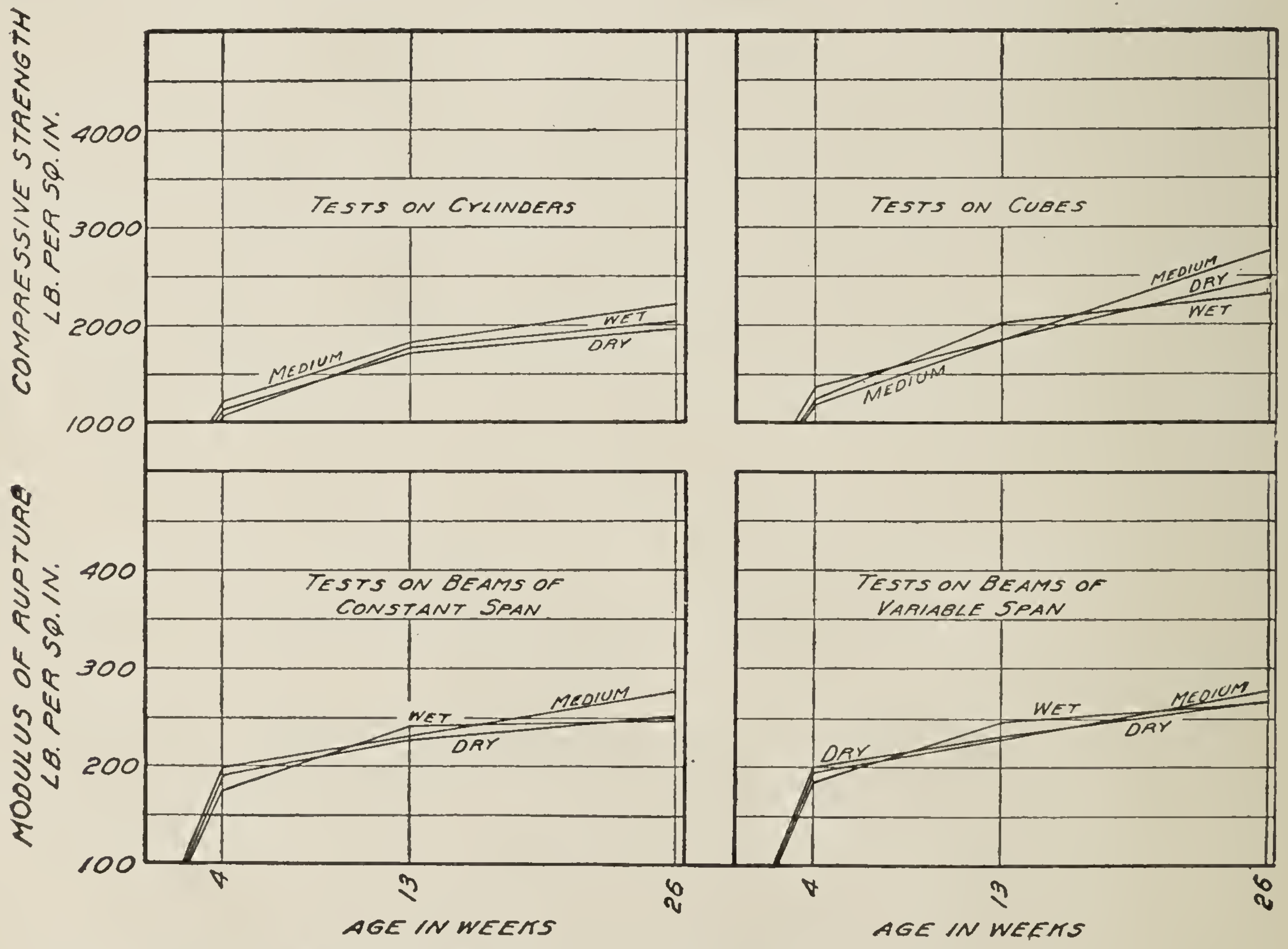


FIG. 2.—Diagrams showing the effect of age and consistency on the strength of cinder concrete.

three ages of 4, 13, and 26 weeks, and some of the results are graphically shown in figs. 2–5 and 10–13.

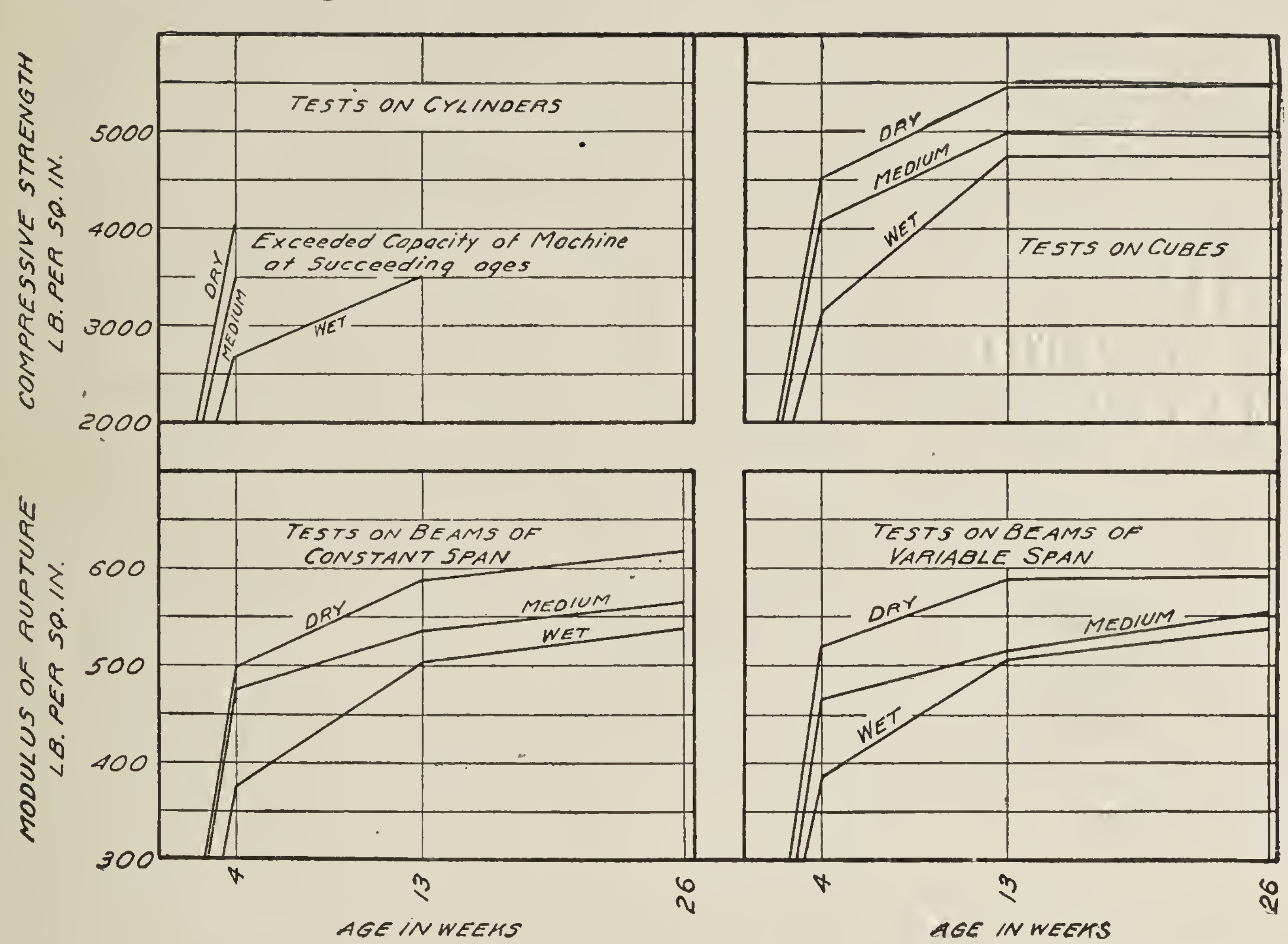


FIG. 3.—Diagrams showing the effect of age and consistency on the strength of granite concrete.

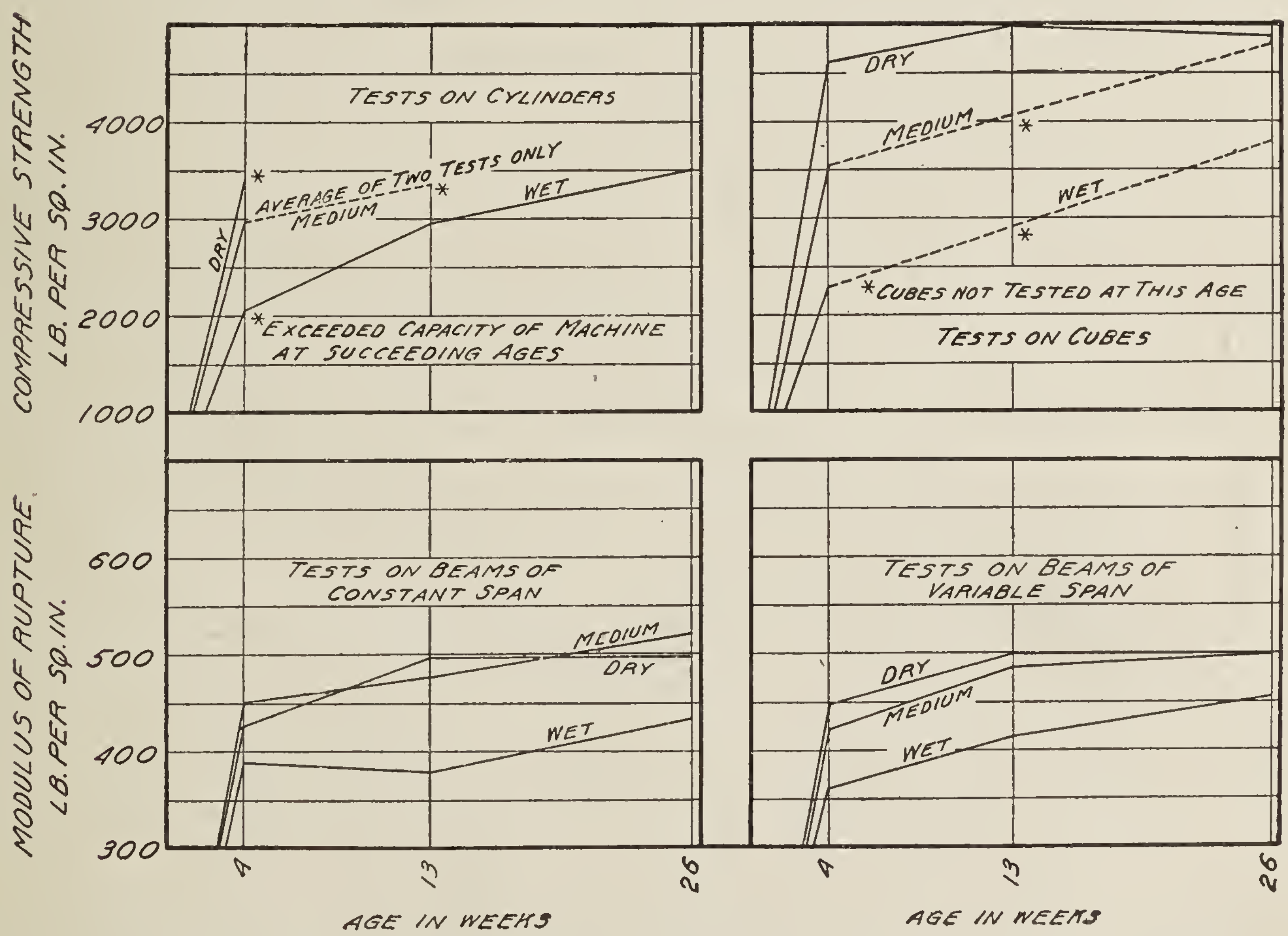


FIG. 4.—Diagrams showing the effect of age and consistency on the strength of gravel concrete.

The percentage of water is expressed in the table in terms of the total weight of the dry material. This percentage includes the weight of the moisture in the sand and aggregate, which varies from

1.5 to 2.0 per cent of the weight of the stone, from 3 to 4 per cent of the weight of the sand, and may include as much as 21 per cent of the weight of the cinders. A simple computation, using the proportions

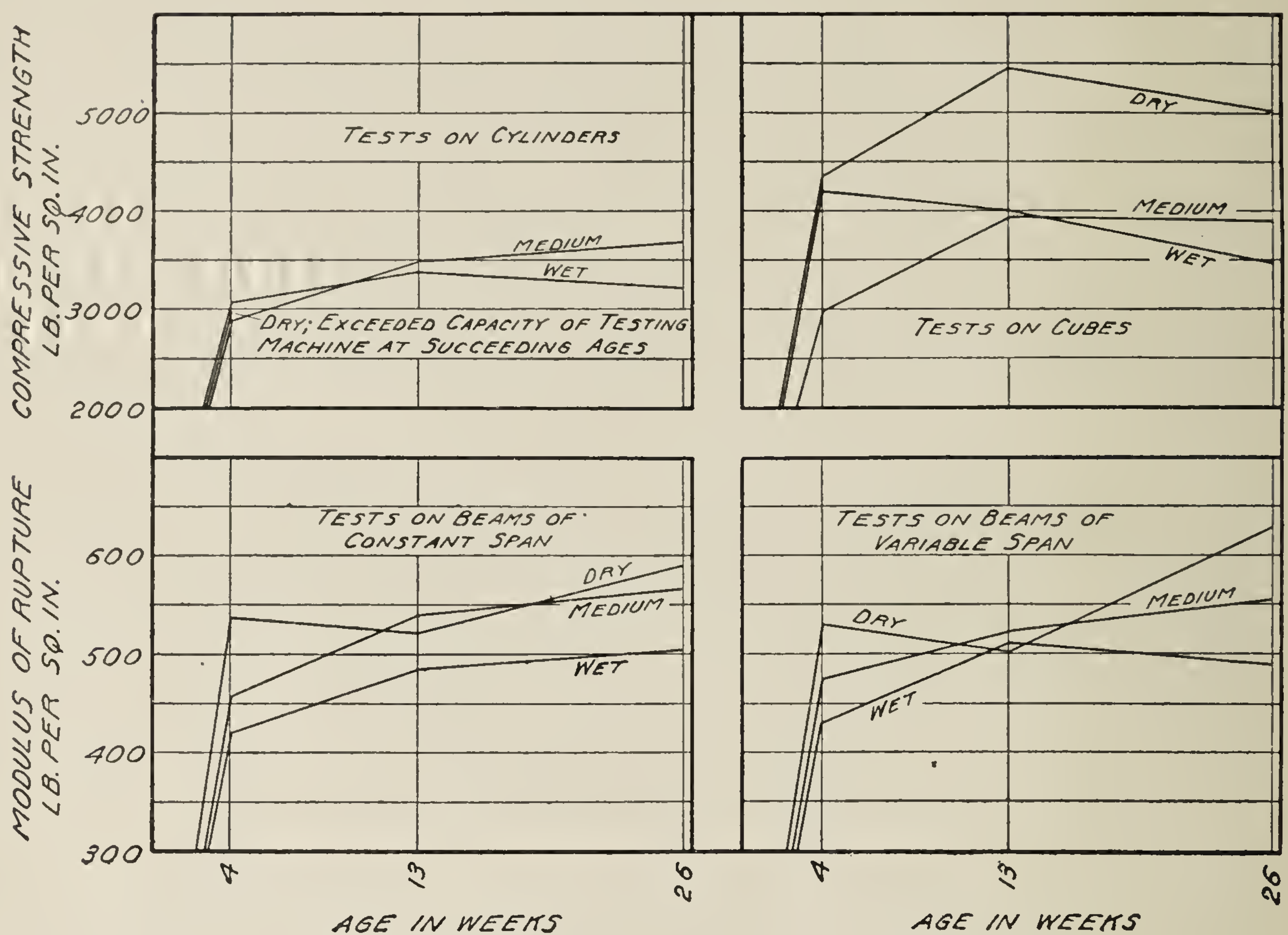


FIG. 5.—Diagrams showing the effect of age and consistency on the strength of limestone concrete.

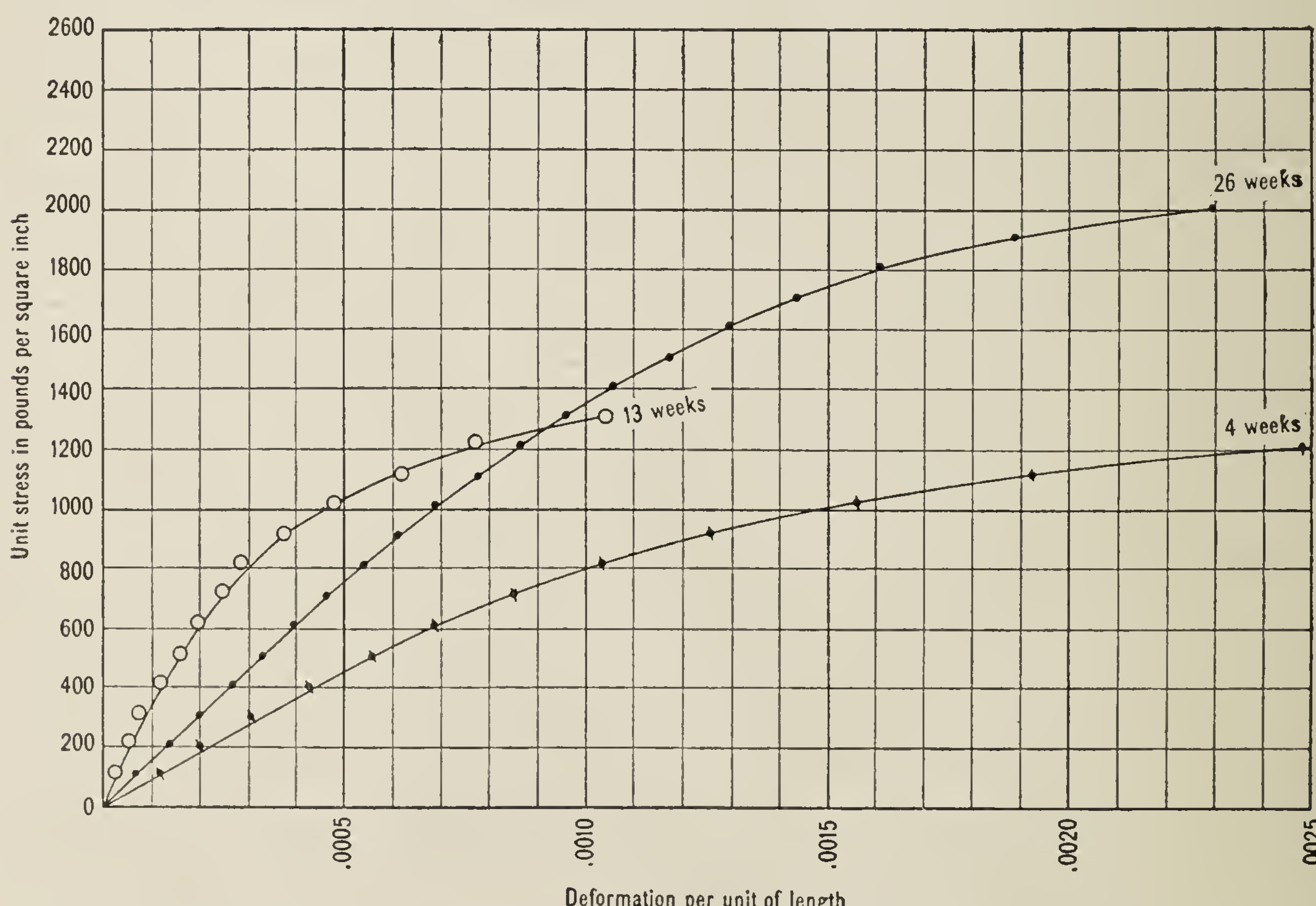


FIG. 6.—Characteristic compression-stress deformation diagrams, cinder concrete of medium consistency; ages 4, 13, and 26 weeks.

by weight, will show that this 21 per cent moisture forms as much as 43 per cent of the total amount of water, including moisture, that is necessary to bring the concrete to the desired consistency. Deduct-

ing this 43 per cent moisture from the total percentage of water leaves about 12 per cent of the total weight of the dry material as the weight of the water added plus the weight of the moisture in the sand. This does not differ so very much from the percentage of water used for the other aggregates. As already indicated, it would seem that the influence of the water present in the stone or cinders and even for usual values of 3 to 4 per cent in the sand does not influence the consistency as greatly as does the same weight of water when added to the batch.

Column 6 of the table gives the consistency of the concrete and must be compared with the definitions of wet, medium, and damp concrete already given (p. 20).

Columns 7, 8, and 9 give the dimensions of the beam, the span being kept constant at 12 feet.

Column 10 gives the total weight of the beam, which is obtained by weighing the beam on the testing machine. The error in weighing is in no case greater than 5 pounds in either direction. Column 11 gives the weight per cubic foot of the beam.

Column 12 gives the unit elongation of the lower fiber when the beam rests freely on a 12-foot span subjected only to its own weight and the weight of the deformeters. This value is obtained by first taking a reading for zero total deformation as already described (p. 23) and a second reading when the beam rests as above. This value is included for the reason that in all tests made up to the present time deformations due to applied load only were read. If it is desired to compare the present tests with others already made the unit elongation as given in column 14, which was measured at a load just previous to rupture, when decreased by the

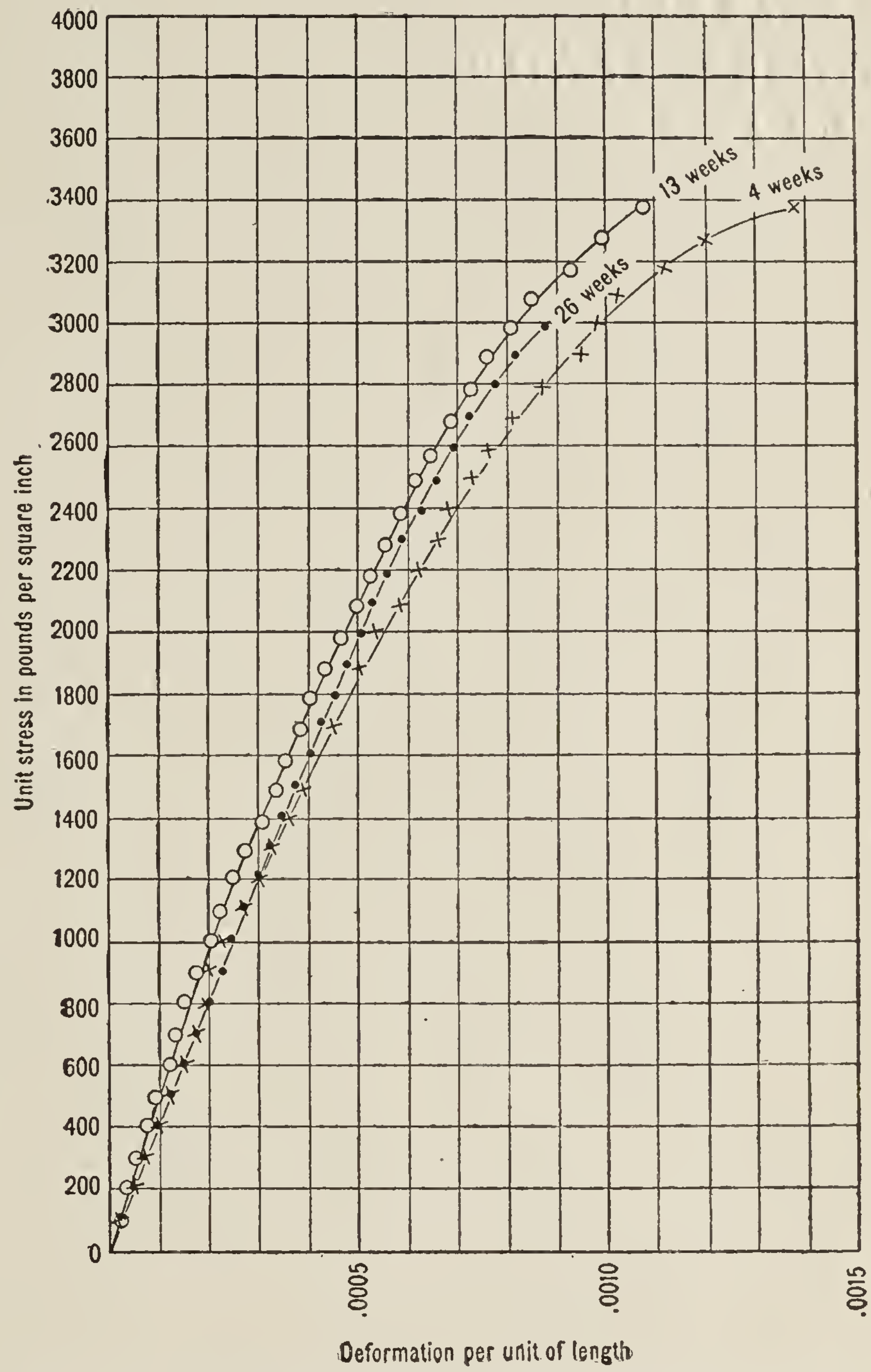


FIG. 7.—Characteristic compression-stress deformation diagrams, granite concrete of medium consistency; ages 4, 13, and 26 weeks.

value in column 12 will give the unit elongation at a point near rupture for the applied load alone.

Column 13 shows $\frac{M}{bd^2}$ (pounds per square inch) for the last load previous to failure. The relation of this value to the breaking value in column 19 is readily seen by comparison. In computing all the values of $\frac{M}{bd^2}$ given in these tables the nominal values 8 inches and 11 inches were used for the breadth (b) and the depth (d) of the beam.

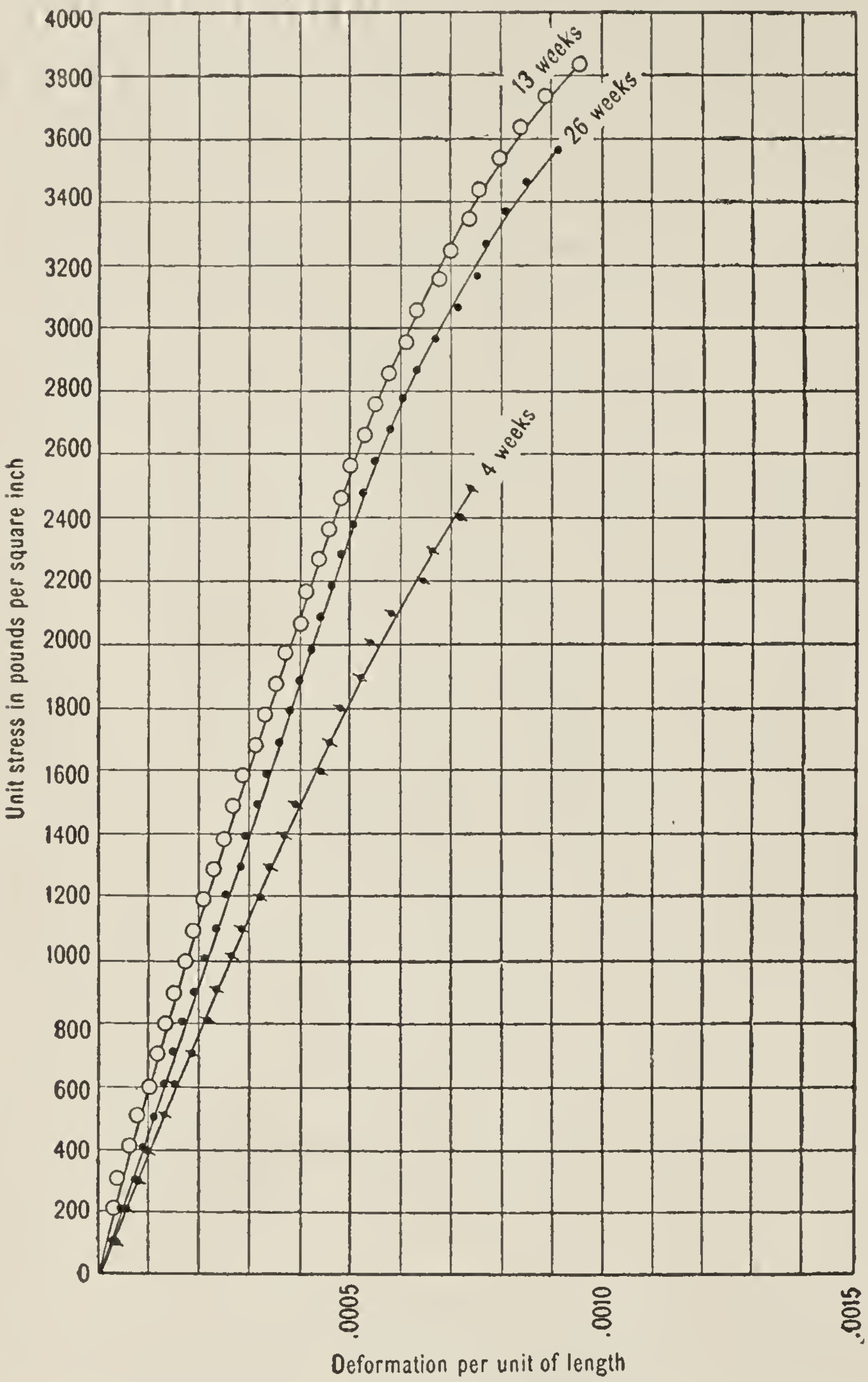


FIG. 8.—Characteristic compression-stress deformation diagrams, gravel concrete of medium consistency; ages 4, 13, and 26 weeks.

Column 14 shows the unit elongation of the lower outer fiber for the load previous to rupture. An unsuccessful attempt was made to obtain an exact value for the unit elongation of the lower fiber at rupture, but it was found impossible to take a reading of the micrometers at the exact instant of the breaking of the beam. Just previous to the break the concrete in the lower fiber elongates so rapidly that it is impossible to revolve the micrometer fast enough to maintain contact with the rod. While the lower micrometers on both sides of the beam may be read as the beam breaks the values obtained are so erratic that they have not been included in the tables of this bulletin.

The unit elongations reported under "Final deformeters" (columns 13, 14, and 15) in Table 8 are the values obtained at the last full set of readings preceding the breaking of the beam, and it must therefore be recognized that while they approximate the elongations at maximum load they are not absolute. Attention is called to the apparent

relation between the values in columns 13 and 14. Separating the aggregates into cinders on one hand and the three stone concretes on the other, the elongation seems to bear a direct relation to $\frac{M}{bd^2}$ or the load carried. This comparison, however, can not be made for the cinders, owing perhaps to the nonuniformity in the strength of the clinker itself.

Column 15 shows the position of the neutral axis for the load preceding failure. This is obtained from the usual assumption of proportionality between deformation and position of the neutral axis.

The maximum load applied at the third points of the span (column 16) excludes the weight of the deformeters. The corresponding $\frac{M}{bd^2}$ is shown in column 17.

Column 18 shows the $\frac{M}{bd^2}$ for the weight of the beam, taking into consideration the effect of the 6-inch overhang on each end and also the constant weight of the deformeters.

Column 19 shows the maximum total $\frac{M}{bd^2}$, which is equal to the sum of the values in columns 17 and 18.

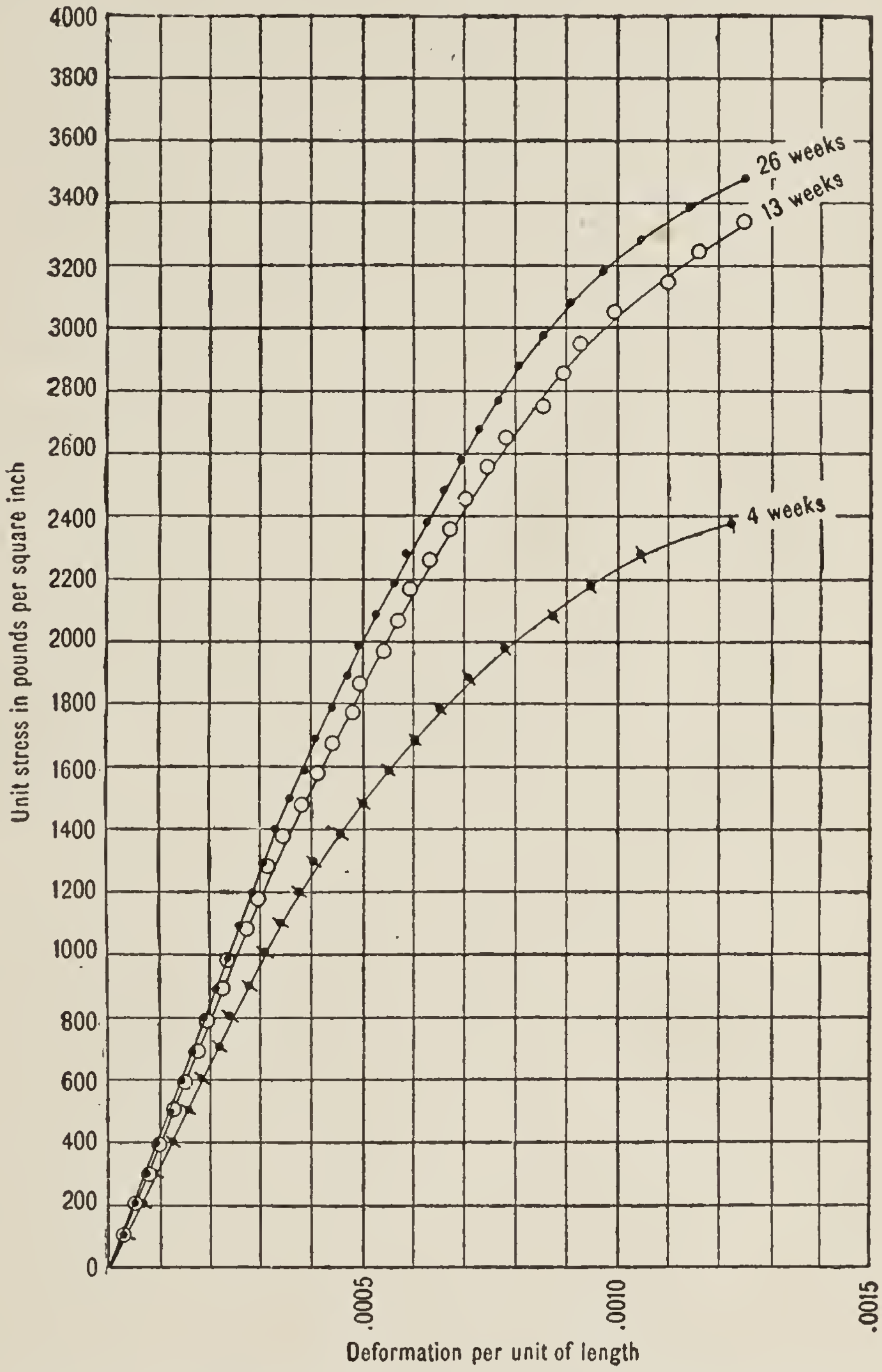


FIG. 9.—Characteristic compression-stress deformation diagrams, limestone concrete of medium consistency; ages 4, 13, and 26 weeks.

Column 20 shows the modulus of rupture in pounds per square inch. These values were obtained by multiplying those in column 19 by 6. The method of computing the modulus of rupture should be emphasized. It is based on the assumption that the coefficients of elasticity in tension and compression are equal and constant and that

consequently the neutral axis remains in the center of the beam. An examination of the table shows, however, that the neutral axis actually varies from 30.4 to 63.0 per cent of the depth of the beam below the top.

Column 21 gives the distance of the break from the center of the beam, which in few cases is more than 1 foot.

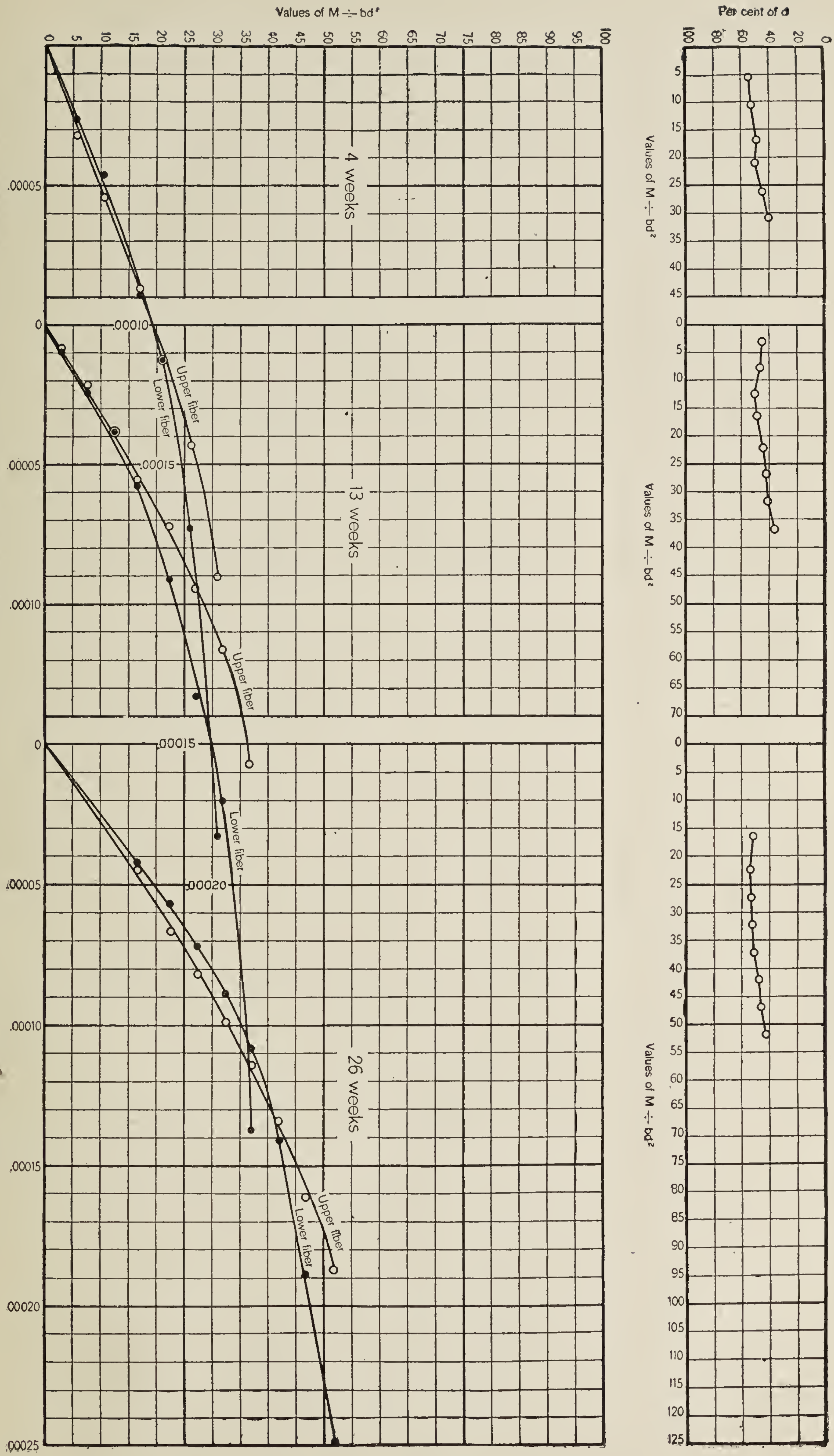


FIG. 10.—Characteristic deformation curves for flexure, cinder concrete of medium consistency; ages 4, 13, and 26 weeks.

TABLE 8.—*Tests of 13-foot concrete beams of constant 12-foot span.*

TESTED AT FOUR WEEKS.

Register No.	Aggregate.	Proportion. Volume.	Proportion. Weight.	Water (per cent).	Consistency.	Dimensions of beam (inches). Length in excess of 13 feet.	Dimensions of beam (inches). Section. Wide.	Dimensions of beam (inches). Section. Deep.	Weight (pounds). Total.	Weight (pounds). Per cubic foot.	Unit elongation, lower outer fiber (own weight + deformeters).	Final deformeters. $\frac{M}{bd^2}$ (total).	Final deformeters. Unit elongation, lower outer fiber.	Final deformeters. Position neutral axis.	Maximum applied. Load.	Maximum applied. $\frac{M}{bd^2}$ (center).	Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$.	Distance of break from center (inches).
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
18	Cinder	1:2:5.06	1:2.02:2.38	21.6	Wet	0	$8\frac{1}{16}$	11	940	117.4	0.000092	25.95	0.000200	42.5	510	12.54	17.10	29.64	178	37
19	do	1:2:5.06	1:2.02:2.38	21.8	do	$\frac{3}{8}$	8	11	960	120.5	.000096	31.46	.000299	39.2	560	13.89	17.57	31.46	189	4
21	do	1:2:5.06	1:2.02:2.38	21.6	do	$\frac{3}{8}$	8	11	950	119.3	.000108	21.37	.000168	43.8	360	8.93	17.40	26.33	158	11
Average									950	119.1	.000099	26.26	.000222	41.8	477	11.79	17.36	29.14	175	
24	do	1:2:5.06	1:2.02:2.38	19.4	Med	$\frac{3}{8}$	8	11	910	114.3	.000096	35.57	.000430	35.0	760	18.85	16.72	35.57	213	2
28	do	1:2.06:5.40	1:2.07:2.54	20.4	do	$\frac{1}{2}$	8	11	900	112.9	.000100	30.43	.000263	43.9	640	15.87	16.55	32.42	195	0
29	do	1:2.06:5.40	1:2.07:2.54	20.4	do	$\frac{1}{4}$	8	11	920	115.6	.000089	30.77	.000283	40.3	560	13.88	16.89	30.77	185	3
Average									910	114.3	.000095	32.26	.000335	39.7	653	16.20	16.72	32.92	198	
37	do	1:2:5.19	1:2.01:2.44	19.0	Damp.	$\frac{1}{2}$	$8\frac{1}{4}$	11	920	111.9	.000110	29.84	.000329	38.0	620	14.90	16.38	31.28	188	2
38	do	1:2:5.19	1:2.01:2.44	19.0	do	$\frac{1}{4}$	8	$11\frac{1}{4}$	940	115.5	.000125	29.75	.000374	36.2	660	15.65	16.47	32.12	193	18
39	do	1:2:5.19	1:2.01:2.44	19.0	do	$\frac{5}{8}$	8	$11\frac{1}{8}$	940	115.1	.000097	35.27	.000377	37.3	780	18.42	16.85	35.27	212	6
Average									933	114.2	.000111	31.62	.000360	37.2	687	16.32	16.57	32.89	198	
53	Granite	1:2:4	1:2.01:3.82	9.2	Wet	$\frac{1}{2}$	$8\frac{1}{16}$	$11\frac{1}{8}$	1,220	150.2	.000024	58.38	.000067	63.5	1,840	44.26	21.34	65.60	394	13
54	do	1:2:4	1:2.01:3.82	9.0	do	$\frac{3}{8}$	$7\frac{15}{16}$	$11\frac{1}{4}$	1,170	144.8	.000034	58.37	.000094	43.8	1,710	40.86	20.38	61.24	367	6
55	do	1:2:4	1:2.01:3.82	9.0	do	$\frac{5}{8}$	8	11	1,170	146.7	.000022	60.58	.000079	52.6	1,590	39.43	21.15	60.58	363	0
Average									1,187	147.2	.000027	59.11	.000080	53.3	1,713	41.52	20.96	62.47	375	
51	do	1:2:4	1:2.01:3.80	7.3	Med	$\frac{5}{8}$	8	$11\frac{1}{8}$	1,190	147.5	.000028	76.04	.000120	49.3	2,470	59.88	21.01	80.89	485	18
64	do	1:2:4	1:2.01:3.82	8.4	do	$\frac{1}{2}$	$8\frac{1}{16}$	$11\frac{1}{16}$	1,190	147.3	.000031	78.73	.000128	46.0	2,370	57.64	21.09	78.73	472	8
65	do	1:2:4	1:2.01:3.82	8.4	do	$\frac{1}{2}$	8	$11\frac{1}{8}$	1,240	153.8	.000028	68.39	.000097	49.1	2,320	56.23	21.85	78.08	468	19
Average									1,207	149.5	.000029	74.39	.000115	48.1	2,387	57.92	21.32	79.23	475	
72	do	1:2:4	1:2.01:3.82	6.9	Damp.	$\frac{1}{2}$	$7\frac{15}{16}$	$10\frac{7}{8}$	1,160	148.3	.000018	72.20	.000103	60.4	2,400	60.88	21.47	82.35	494	8
73	do	1:2:4	1:2.01:3.82	6.9	do	$\frac{3}{8}$	8	$11\frac{1}{4}$	1,220	149.8	.000029	67.02	.000120	43.5	2,340	55.46	21.04	76.50	459	2
78	do	1:2:4	1:2.01:3.82	6.9	do	$\frac{1}{4}$	8	$11\frac{3}{16}$	1,220	150.8	.000024	86.94	.000135	50.6	2,890	69.27	21.27	90.54	543	8
Average									1,200	149.6	.000024	75.39	.000119	51.5	2,543	61.87	21.26	83.13	499	

88	Gravel	1:2:4	1:2.01:4.10	9.5	Wet	$\frac{1}{4}$	8	11	1,110	139.5	.000025	66.00	.000096	52.9	1,850	45.87	20.13	66.00	396	12
89 [a]	do	1:2:4	1:2.01:4.10	9.5	do	$\frac{1}{4}$														
90	do	1:2:4	1:2.01:4.10	9.7	do	$\frac{1}{4}$	$8\frac{1}{16}$	$11\frac{1}{16}$	1,150	142.6	.000028	59.58	.000088	46.4	1,810	44.02	20.42	64.44	387	8
Average									1,130	141.1	.000027	62.79	.000092	49.7	1,830	44.95	20.27	65.22	391	
100	do	1:2:4	1:2.01:4.10	8.6	Med	$\frac{5}{8}$	$7\frac{15}{16}$	$11\frac{1}{8}$	1,140	142.4	.000025	69.69	.000090	50.5	2,420	59.12	20.34	79.46	477	16
101	do	1:2:4	1:2.01:4.10	8.6	do	$\frac{1}{4}$	$8\frac{1}{16}$	$11\frac{1}{4}$	1,130	137.8	.000026	67.16	.000095	47.2	2,380	55.97	19.42	75.39	452	1
102	do	1:2:4	1:2.01:4.10	9.0	do	$\frac{1}{4}$	$8\frac{1}{16}$	$10\frac{15}{16}$	1,160	145.5	.000023	70.85	.000100	50.0	2,000	49.77	21.06	70.83	425	15
Average									1,143	141.2	.000025	69.23	.000095	49.2	2,267	54.95	20.27	75.23	451	
112	do	1:2:4	1:2.01:4.10	7.6	Damp	$\frac{1}{2}$	8	11	1,110	139.3	.000023	61.04	.000088	49.0	2,050	50.83	20.13	70.96	426	7
113	do	1:2:4	1:2.01:4.10	7.6	do	$\frac{1}{4}$	8	$11\frac{1}{8}$	1,150	142.9	.000021	59.37	.000082	47.3	2,010	48.72	20.35	69.07	414	6
115	do	1:2:4	1:2.01:4.10	7.6	do	$\frac{1}{2}$	$8\frac{1}{16}$	$10\frac{13}{16}$	1,110	140.6	.000035	62.68	.000109	41.8	2,050	52.20	20.67	72.87	437	0
Average									1,123	140.9	.000026	61.03	.000093	46.0	2,037	50.58	20.38	70.97	426	
128	Limestone	1:2:4	1:2.01:3.91	10.8	Wet	$\frac{3}{8}$	$8\frac{1}{16}$	$11\frac{1}{16}$	1,170	145.0	.000032	69.16	.000119	47.7	2,390	58.13	20.75	78.88	473	8
129	do	1:2:4	1:2.01:3.91	10.8	do	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{5}{16}$	1,150	139.1	.000023	66.29	.000101	53.2	2,010	46.76	19.53	66.29	398	5
130	do	1:2:4	1:2.01:3.91	11.0	do	$\frac{1}{2}$	8	$11\frac{3}{8}$	1,170	142.0	.000026	56.64	.000084	50.9	1,990	46.14	19.78	65.92	396	5
Average									1,163	142.0	.000027	64.03	.000101	50.6	2,130	50.34	20.02	70.36	422	
141	do	1:2:4	1:2.01:3.91	10.0	Med	$\frac{1}{2}$	$8\frac{1}{16}$	$11\frac{3}{16}$	1,170	143.2	.000028	77.13	.000127	51.4	2,390	56.84	20.29	77.13	463	6
142	do	1:2:4	1:2.01:3.91	10.0	do	$\frac{3}{8}$	8	$11\frac{1}{16}$	1,170	146.1	.000028	69.70	.000114	49.1	2,030	49.77	20.91	70.68	424	15
143	do	1:2:4	1:2.01:3.91	10.0	do	$\frac{5}{8}$	$7\frac{15}{16}$	11	1,170	147.8	.000032	71.05	.000110	51.4	2,390	59.72	21.32	81.04	486	3
Average									1,170	145.7	.000029	72.63	.000117	50.6	2,270	55.44	20.84	76.28	458	
150	do	1:2:4	1:2.01:3.91	8.4	Damp	$\frac{5}{8}$	8	$11\frac{3}{16}$	1,170	144.2	.000026	87.32	.000125	52.6	3,190	76.45	20.45	96.90	581	5
151	do	1:2:4	1:2.01:3.91	8.4	do	$\frac{3}{8}$	8	11	1,140	143.2	.000027	80.64	.000136	45.5	2,800	69.42	20.64	90.06	540	5
152	do	1:2:4	1:2.01:3.91	8.4	do	$\frac{1}{2}$	8	$11\frac{1}{16}$	1,150	143.5	.000038	79.66	.000142	48.0	2,500	61.28	20.58	81.86	491	15
Average									1,153	143.6	.000030	82.54	.000134	48.7	2,830	69.05	20.56	89.61	537	

[a] Accidentally broken before test.

TABLE 8.—*Tests of 13-foot concrete beams of constant 12-foot span*—Continued.

TESTED AT THIRTEEN WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Dimensions of beam (inches).			Weight (pounds).		Unit elongation, lower outer fiber (own weight + deformeters).	Final deformeters.			Maximum applied.		Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$.	Distance of break from center (inches).
		Volume.	Weight.			Length in excess of 13 feet.	Section. Wide.	Section. Deep.	Total.	Per cubic foot.		$\frac{M}{bd^2}$ (total).	Unit elongation, lower outer fiber.	Position neutral axis.	Load.	$\frac{M}{bd^2}$ (center).				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	Cinders	1:2:4.86	1:2.02:2.29	22.15	Wet	$\frac{5}{8}$	8	$11\frac{3}{16}$	960	118.4	0.000042	36.16	0.000142	47.8	890	21.33	16.99	38.32	230	15
8	do	1:2:4.79	1:2.02:2.25	22.3	do	$\frac{1}{2}$	8	$11\frac{1}{8}$	940	116.6	.000053	36.72	.000200	41.8	1,010	24.48	16.85	41.33	248	14
9	do	1:2:4.79	1:2.02:2.25	22.0	do	$\frac{5}{8}$	8	$11\frac{1}{8}$	930	115.3	.000066	36.80	.000275	37.4	980	23.76	16.68	40.44	243	21
Average									943	116.8	.000054	36.56	.000206	42.3	960	23.19	16.84	40.03	240	
3	Cinders	1:2:5.13	1:2.02:2.41	21.4	Med	$\frac{3}{8}$	8	$11\frac{1}{8}$	920	114.2	.000051	41.72	.000284	37.6	1,180	28.61	16.51	45.12	271	10
33	do	1:2:5.21	1:2.01:2.45	21.0	do	$\frac{1}{2}$	8	$11\frac{1}{16}$	920	114.8	.000073	32.39	.000293	36.9	700	17.16	16.70	33.86	203	9
34	do	1:2:5.21	1:2.01:2.45	20.0	do	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{1}{8}$	930	114.4	.000058	36.51	.000287	35.4	830	19.96	16.55	36.51	219	2
Average									923	114.5	.000061	36.87	.000288	36.6	903	21.91	16.59	38.50	231	
40	Cinders	1:2:5.19	1:2.01:2.44	19.0	Damp	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{1}{4}$	940	114.3	.000062	35.63	.000238	38.8	890	20.93	16.35	37.28	224	19
41	do	1:2:5.19	1:2.01:2.44	19.0	do	$\frac{1}{4}$	8	$11\frac{1}{8}$	940	116.8	.000073	36.72	.000320	36.0	930	22.54	16.85	39.39	236	15
42	do	1:2:5.19	1:2.01:2.44	18.9	do	$\frac{5}{8}$	8	$11\frac{1}{16}$	930	115.9	.000091	32.32	.000292	33.2	780	19.12	16.87	35.99	216	3
Average									937	115.7	.000075	34.89	.000283	36.0	867	20.86	16.69	37.55	225	
56	Granite	1:2:4	1:2.01:3.82	8.7	Wet	$\frac{1}{4}$	8	$11\frac{1}{8}$	1,200	149.1	.000023	68.69	.000078	52.6	2,310	55.99	21.18	77.17	463	16
57	do	1:2:4	1:2.01:3.82	8.7	do	$\frac{1}{2}$	8	$11\frac{1}{16}$	1,200	149.7	.000026	89.08	.000129	48.3	2,760	67.66	21.42	89.08	534	3
58	do	1:2:4	1:2.01:3.82	9.0	do	$\frac{3}{8}$	$8\frac{1}{16}$	$11\frac{1}{16}$	1,200	148.7	.000028	78.66	.000131	44.1	2,600	63.25	21.25	84.50	507	6
Average									1,200	149.2	.000026	78.81	.000113	48.3	2,557	62.30	21.28	83.58	501	
68	Granite	1:2:4	1:2.01:3.82	8.2	Med	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{3}{8}$	1,240	149.2	.000023	74.10	.000096	50.0	2,710	62.34	20.73	83.07	498	18
69	do	1:2:4	1:2.01:3.82	8.2	do	$\frac{3}{8}$	$8\frac{1}{16}$	$11\frac{3}{16}$	1,240	151.9	.000026	86.12	.000119	45.7	3,120	74.20	21.44	95.64	574	5
70	do	1:2:3.97	1:2.01:3.78	8.6	do	$\frac{3}{8}$	8	$11\frac{5}{8}$	1,220	145.0	.000021	80.50	.000111	48.8	3,140	69.68	19.70	89.38	536	4
Average									1,233	148.7	.000023	80.24	.000109	48.2	2,990	68.74	20.62	89.36	536	
79	Granite	1:2:4	1:2.01:3.82	6.9	Damp	$\frac{3}{8}$	$8\frac{1}{16}$	11	1,160	144.5	.000032	89.70	.000160	44.0	3,050	75.03	20.82	95.85	575	16
80	do	1:2:4	1:2.01:3.82	7.0	do	$\frac{1}{2}$	$8\frac{1}{16}$	$11\frac{3}{16}$	1,200	146.9	.000024	95.94	.000162	43.7	3,400	80.87	20.78	101.65	610	9
81	do	1:2:4	1:2.01:3.82	7.0	do	$\frac{1}{2}$	8	$11\frac{1}{8}$	1,160	143.9	.000024	98.08	.000155	47.1	3,200	77.57	20.51	98.08	588	0
Average									1,173	145.1	.000027	94.57	.000159	44.9	3,217	77.82	20.70	98.53	591	

91	Gravel	1:2:4	1:2.01:4.10	9.7	Wet	$\frac{1}{2}$	$7\frac{15}{16}$	$11\frac{3}{8}$	1,160	141.9	.000017	57.17	.000062	52.6	2,000	46.73	19.78	66.51	399	6
92	do	1:2:4	1:2.01:4.10	9.9	do	$\frac{7}{8}$	8	11	1,160	145.2	.000023	50.74	.000057	54.1	1,410	34.96	20.98	55.94	336	24
93	do	1:2:4	1:2.01:4.10	9.9	do	$\frac{3}{8}$	8	$11\frac{1}{4}$	1,170	143.7	.000026	57.91	.000081	46.6	1,990	47.17	20.22	67.39	404	11
Average									1,163	143.6	.000022	55.27	.000067	51.1	1,800	42.95	20.33	63.28	380	
103	Gravel	1:2:4	1:2.01:4.10	9.0	Med	$\frac{1}{2}$	$8\frac{1}{16}$	$10\frac{15}{16}$	1,170	146.5	.000021	70.62	.000082	55.5	2,330	57.73	20.86	78.59	472	14
104	do	1:2:4	1:2.01:4.10	9.0	do	$\frac{3}{8}$	8	$11\frac{1}{16}$	1,150	143.6	.000024	79.55	.000112	45.9	2,430	59.34	20.21	79.55	477	8
105	do	1:2:4	1:2.01:4.10	9.0	do	$\frac{1}{2}$	$7\frac{15}{16}$	$11\frac{1}{16}$	1,140	143.3	.000021	80.24	.000106	51.9	2,440	60.14	20.10	80.24	481	2
Average									1,153	144.5	.000022	76.80	.000100	51.1	2,400	59.07	20.39	79.46	477	
116	Gravel	1:2:4	1:2.01:4.10	7.6	Damp.	$\frac{1}{2}$	$8\frac{1}{16}$	$10\frac{15}{16}$	1,140	142.7	.000026	80.81	.000132	45.5	2,490	61.71	20.35	82.06	492	4
117	do	1:2:4	1:2.01:4.10	8.0	do	$\frac{5}{8}$	8	$10\frac{15}{16}$	1,150	145.0	.000025	81.37	.000122	48.2	2,430	60.69	20.68	81.37	488	3
118	do	1:2:4	1:2.01:4.10	8.1	do	$\frac{1}{2}$	$7\frac{15}{16}$	$10\frac{13}{16}$	1,120	144.1	.000029	73.80	.000105	46.0	2,460	63.10	21.05	84.15	515	24
Average									1,137	143.9	.000027	78.66	.000120	46.6	2,460	61.83	20.69	82.53	495	
131	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	$\frac{1}{2}$	8	$11\frac{1}{8}$	1,190	147.6	.000028	68.65	.000096	49.5	2,260	54.79	20.41	75.20	451	5
132	do	1:2:4	1:2.01:3.91	11.0	do	$\frac{3}{4}$	$7\frac{15}{16}$	11	1,170	147.7	.000026	80.93	.000116	49.3	2,760	68.97	20.70	89.67	538	10
133	do	1:2:4	1:2.01:3.91	11.0	do	$\frac{1}{4}$	8	$11\frac{1}{8}$	1,180	146.6	.000024	68.72	.000094	48.6	2,400	58.18	20.24	78.42	471	19
Average									1,180	147.3	.000026	72.77	.000102	49.1	2,473	60.65	20.45	81.10	487	
126	Limestone	1:2:4	1:2.01:3.91	10.4	Med	$\frac{1}{2}$	8	$11\frac{1}{16}$	1,150	143.5	.000025	89.35	.000142	44.6	2,830	69.38	19.97	89.35	536	0
127	do	1:2:4	1:2.01:3.91	10.4	do	$\frac{1}{2}$	8	$11\frac{5}{16}$	1,200	146.4	.000026	94.44	.000124	50.4	3,180	74.54	19.90	94.44	567	3
140	do	1:2:4	1:2.01:3.91	10.0	do	$\frac{3}{4}$	$7\frac{15}{16}$	$11\frac{1}{8}$	1,170	146.1	.000018	79.11	.000096	56.6	2,710	66.70	20.24	86.44	519	10
Average									1,173	145.3	.000023	87.63	.000121	50.5	2,907	70.04	20.04	90.08	541	
153	Limestone	1:2:4	1:2.01:3.91	8.4	Damp.	$\frac{5}{8}$	8	$10\frac{7}{8}$	1,150	144.0	.000026	82.30	.000155	44.5	2,620	66.47	20.66	87.13	523	12
154	do	1:2:4	1:2.01:3.91	8.4	do	$\frac{5}{8}$	$7\frac{15}{16}$	$10\frac{15}{16}$	1,150	146.1	.000032	82.00	.000136	46.3	2,430	61.41	20.59	82.00	492	22
155	do	1:2:4	1:2.01:3.91	8.4	do	$\frac{5}{8}$	8	$10\frac{15}{16}$	1,160	146.3	.000034	91.32	.000138	48.5	2,820	70.72	20.60	91.32	548	15
Average									1,153	145.5	.000031	85.21	.000143	46.4	2,623	66.20	20.62	86.82	521	

TABLE 8.—*Tests of 13-foot concrete beams of constant 12-foot span*—Continued.

TESTED AT TWENTY-SIX WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Dimensions of beam (inches).			Weight (pounds).		Unit elongation, lower outer fiber (own weight + deformeters).	Final deformeters.			Maximum applied.		Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$.	Distance of break from center (inches).
		Volume.	Weight.			Length in excess of 13 feet.	Section. Wide.	Section. Deep.	Total.	Per cubic foot.		$\frac{M}{bd^2}$ (total).	Unit elongation, lower outer fiber.	Position neutral axis.	Load.	$\frac{M}{bd^2}$ (center).				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
12	Cinder	1:2:4.79	1:2.02:2.25	22.4	Wet	$\frac{5}{8}$	8	$11\frac{1}{16}$	930	115.9	0.000045	40.78	0.000216	44.0	1,020	25.01	16.26	41.27	248	5
15	do	1:2:4.79	1:2.02:2.25	22.4	do	$\frac{1}{2}$	8	$10\frac{7}{8}$	900	114.2	.000045	36.60	.000146	47.9	950	24.09	16.31	40.40	242	11
16	do	1:2:5.06	1:2.02:2.38	21.3	do	$\frac{3}{8}$	$8\frac{1}{16}$	$11\frac{1}{16}$	910	112.8	.000047	40.13	.000186	42.6	1,050	25.54	15.80	41.34	248	2
Average									913	114.3	.000046	39.17	.000183	44.8	1,007	24.88	16.12	41.00	246	
5	Cinder	1:2:4.79	1:2.02:2.25	21.7	Med	$\frac{5}{8}$	8	$11\frac{1}{16}$	940	117.2	.000042	51.73	.000249	42.9	1,440	35.30	16.43	51.73	310	6
6	do	1:2:4.79	1:2.02:2.25	21.7	do	$\frac{1}{2}$	8	$11\frac{1}{16}$	930	116.0	.000041	42.00	.000180	43.5	1,210	29.67	16.26	45.93	276	10
35	do	1:2:5.21	1:2.01:2.45	20.0	do	$\frac{3}{8}$	8	$11\frac{1}{16}$	930	116.1	.000051	40.78	.000371	34.0	1,000	24.52	16.26	40.78	245	4
Average									933	116.4	.000045	44.84	.000267	40.1	1,217	29.83	16.32	46.15	277	
43	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{3}{16}$	910	111.3	.000049	39.23	.000265	40.8	1,150	27.35	15.45	42.80	257	6
44	do	1:2:5.19	1:2.01:2.44	19.0	do	$\frac{5}{8}$	8	$11\frac{1}{8}$	920	114.0	.000047	40.15	.000299	38.2	1,040	25.21	15.91	41.12	247	6
45	do	1:2:5.19	1:2.01:2.44	18.5	do	$\frac{3}{4}$	$8\frac{1}{16}$	$11\frac{1}{8}$	910	111.8	.000049	39.67	.000266	38.5	1,050	25.26	15.62	40.88	245	4
Average									913	112.4	.000048	39.68	.000277	39.2	1,080	25.94	15.66	41.60	250	
59	Granite	1:2:4	1:2.01:3.82	9.0	Wet	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{1}{2}$	1,220	145.2	.000021	86.94	.000132	45.8	3,000	67.52	19.42	86.94	522	22
60	do	1:2:4	1:2.01:3.82	8.8	do	$\frac{3}{8}$	8	$11\frac{3}{16}$	1,230	151.9	.000022	92.76	.000137	47.1	3,000	71.92	20.84	92.76	557	3
61	do	1:2:4	1:2.01:3.82	9.0	do	$\frac{3}{4}$	$8\frac{1}{16}$	$11\frac{3}{16}$	1,230	150.3	.000019	a 44.47	a .000060	a 48.5	a 1,300	a 30.92	20.68	a 51.60	a 310	1
Average									1,227	149.1	.000021	89.85	.000134	46.4	3,000	69.72	20.31	89.85	539	
71	Granite	1:2:3.97	1:2.01:3.78	8.6	Med	$\frac{3}{4}$	$8\frac{1}{16}$	$11\frac{7}{16}$	1,250	149.4	.000021	88.39	.000114	48.1	3,170	72.16	20.11	92.27	554	8
74	do	1:2:4	1:2.01:3.82	8.4	do	$\frac{1}{2}$	8	$11\frac{3}{16}$	1,220	150.5	.000024	92.60	.000141	44.3	3,280	78.62	20.68	99.30	596	15
75	do	1:2:4	1:2.01:3.82	8.4	do	$\frac{3}{4}$	8	$11\frac{1}{4}$	1,200	147.0	.000021	91.24	.000142	46.5	3,000	71.11	20.13	91.24	547	2
Average									1,223	149.0	.000022	90.74	.000132	46.3	3,150	73.96	20.31	94.27	566	
82	Granite	1:2:4	1:2.01:3.82	7.0	Damp	$\frac{5}{8}$	8	$11\frac{1}{8}$	1,190	147.5	.000019	105.25	.000161	46.9	3,500	84.84	20.41	105.25	631	19
83	do	1:2:4	1:2.01:3.82	7.0	do	$\frac{5}{8}$	$8\frac{1}{8}$	$11\frac{1}{16}$	1,190	146.1	.000023	92.74	.000147	44.2	3,350	80.87	20.33	101.20	607	15
84	do	1:2:4	1:2.01:3.82	7.1	do	$\frac{1}{2}$	$8\frac{1}{8}$	$11\frac{3}{8}$	1,230	146.9	.000021	99.76	.000166	44.3	3,630	82.86	19.85	102.71	616	4
Average									1,203	146.8	.000021	99.25	.000158	45.1	3,493	82.86	20.20	103.05	618	

94	Gravel	1:2:4	1:2.01:4.10	9.9	Wet	$\frac{5}{8}$	$8\frac{1}{8}$	$11\frac{7}{16}$	1,150	136.4	.000021	63.55	.000076	53.2	2,500	56.45	18.39	74.84	449	14
95	do	1:2:4	1:2.01:4.10	9.9	do	$\frac{5}{8}$	8	$11\frac{5}{16}$	1,140	139.0	.000024	65.82	.000090	48.0	2,000	46.89	18.93	65.82	395	14
96	do	1:2:4	1:2.01:4.10	9.9	do	$\frac{1}{2}$	$8\frac{1}{8}$	$11\frac{5}{16}$	1,170	140.5	.000021	76.82	.000099	49.1	2,500	57.70	19.12	76.82	461	14
Average	......	......	......	......	......	......	......	......	1,153	138.6	.000022	68.73	.000088	50.1	2,333	53.68	18.81	72.49	435	......
106	Gravel	1:2:4	1:2.01:4.10	9.1	Med.	$\frac{5}{8}$	8	$11\frac{1}{16}$	1,140	142.1	.000026	81.10	.000107	47.5	2,900	71.10	19.80	90.90	545	4
107	do	1:2:4	1:2.01:4.10	9.1	do	$\frac{5}{8}$	$8\frac{1}{8}$	$11\frac{5}{16}$	1,150	138.0	.000023	76.50	.000097	47.7	2,900	66.94	18.80	85.74	514	1
108	do	1:2:4	1:2.01:4.10	9.0	do	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{1}{8}$	1,160	142.7	.000019	79.88	.000109	47.5	2,650	63.73	19.76	83.49	501	14
Average	......	......	......	......	......	......	......	......	1,150	140.9	.000023	79.16	.000104	47.6	2,817	67.26	19.45	86.71	520	......
119	Gravel	1:2:4	1:2.01:4.10	8.1	Damp.	$\frac{5}{8}$	$8\frac{1}{8}$	$10\frac{15}{16}$	1,140	141.5	.000021	81.68	.000102	50.0	2,750	67.91	19.94	87.85	527	5
120	do	1:2:4	1:2.01:4.10	8.1	do	$\frac{5}{8}$	$8\frac{1}{8}$	11	1,140	140.7	.000023	68.54	.000103	47.8	2,370	57.86	19.72	77.58	465	3
121	do	1:2:4	1:2.01:4.10	8.1	do	$\frac{5}{8}$	$8\frac{1}{16}$	11	1,140	141.8	.000021	a 44.47	a .000062	a 45.5	a 1,450	a 35.67	19.87	a 55.54	a 333	9
Average	......	......	......	......	......	......	......	......	1,140	141.3	.000022	75.11	.000102	48.9	2,560	62.89	19.84	82.72	496	......
134	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	$\frac{5}{8}$	$8\frac{1}{16}$	$11\frac{1}{8}$	1,190	146.4	.000021	80.38	.000111	49.2	2,900	69.75	20.25	90.00	540	1
135	do	1:2:4	1:2.01:3.91	11.0	do	$\frac{3}{4}$	$8\frac{1}{16}$	$11\frac{1}{4}$	1,190	144.5	.000025	a 55.09	a .000081	a 48.9	a 1,500	a 35.28	19.81	a 55.09	a 331	30
136	do	1:2:4	1:2.01:3.91	11.0	do	$\frac{3}{4}$	8	$11\frac{1}{4}$	1,190	145.8	.000024	79.22	.000125	44.7	2,500	59.26	19.96	79.22	475	14
Average	......	......	......	......	......	......	......	......	1,190	145.6	.000023	79.80	.000118	46.9	2,700	64.51	20.01	84.61	507	......
144	Limestone	1:2:4	1:2.01:3.91	10.0	Med.	$\frac{5}{8}$	$8\frac{1}{8}$	$11\frac{1}{8}$	1,180	144.0	.000021	91.54	.000119	53.0	3,000	71.60	19.94	91.54	549	9
145	do	1:2:4	1:2.01:3.91	10.0	do	$\frac{5}{8}$	8	$11\frac{3}{16}$	1,190	146.7	.000026	92.09	.000131	49.4	3,000	71.91	20.18	92.09	553	18
258	do	1:2:4	1:2.01:3.91	10.0	do	$\frac{5}{8}$	8	$11\frac{5}{16}$	1,190	145.1	.000021	90.07	.000109	50.0	3,400	79.69	19.74	99.43	597	23
Average	......	......	......	......	......	......	......	......	1,187	145.3	.000023	91.23	.000120	50.8	3,133	74.40	19.95	94.35	566	......
158	Limestone	1:2:4	1:2.01:3.91	8.6	Damp.	$\frac{5}{8}$	8	$11\frac{3}{16}$	1,210	149.2	.000026	92.42	.000144	46.2	3,200	76.71	20.51	97.22	583	2
259	do	1:2:4	1:2.01:3.91	8.6	do	$\frac{1}{2}$	$8\frac{1}{16}$	11	1,200	149.4	.000023	a 45.48	a .000049	a 50.8	a 1,000	a 24.59	20.89	a 45.48	a 273	21
260	do	1:2:4	1:2.01:3.91	8.6	do	$\frac{1}{2}$	$8\frac{1}{16}$	$11\frac{1}{4}$	1,210	147.3	.000019	90.70	.000111	48.8	3,360	79.04	20.13	99.17	595	1
Average	......	......	......	......	......	......	......	......	1,207	148.6	.000023	91.56	.000127	47.5	3,280	77.88	20.51	98.20	589	......

a Not included in average.

TABLE 9.—*Tests of concrete beams of variable span.*

TESTED AT FOUR WEEKS.

Register No.	Aggregate.	Proportion. Volume.	Proportion. Weight.	Water (per cent).	Consistency.	Dimensions of beam. Length. Ft.	Dimensions of beam. Length. In.	Dimensions of beam. Section (inches). Wide.	Dimensions of beam. Section (inches). Deep.	Span (ft.).	Weight (pounds). Total.	Weight (pounds). Per cubic foot.	Final deformeters. $\frac{M}{bd^2}$ (total).	Final deformeters. Unit elongation, lower outer fiber.	Final deformeters. Position neutral axis.	Maximum applied. Load.	Maximum applied. $\frac{M}{bd^2}$ (center).	Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$	Distance of break from center (inches).
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
18	Cinder	1:2:5.06	1:2.02:2.38	21.6	Wet	9	7	8$\frac{1}{16}$	11	9	693	117.4	21.53	0.000235	32.6	1,400	21.53	9.37	30.90	185	......
19	do	1:2:5.06	1:2.02:2.38	21.8	do	6	10	8	11	6	508	120.5	27.27	.000256	40.5	4,670	28.95	4.25	33.20	199	17
21	do	1:2:5.06	1:2.02:2.38	21.6	do	7	5	8	11	7	542	119.3	22.31	.000191	41.4	2,470	22.97	5.81	28.78	173	......
Average												119.1		.000227	38.2				30.96	186	......
24	Cinder	1:2:5.06	1:2.02:2.38	19.4	Med	6	8	8	11	6	467	114.3	32.23	.000284	38.5	5,520	34.22	4.08	38.30	230	......
28	do	1:2.06:5.40	1:2.07:2.54	20.4	do	6	6	8	11	6	450	112.9	27.27	.000301	38.3	4,400	27.27	4.05	31.32	188	......
29	do	1:2.06:5.40	1:2.07:2.54	20.4	do	6	9	8$\frac{1}{4}$	11	6	478	115.6	19.23	.000120	36.4	3,920	23.56	3.98	27.54	165	......
Average												114.3		.000235	37.7				32.39	194	......
37	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	6	6	8$\frac{1}{4}$	11	6	460	111.9	26.44	.000297	36.9	4,400	26.44	4.01	30.45	183	7
38	do	1:2:5.19	1:2.01:2.44	19.0	do	8	0	8	11$\frac{1}{4}$	7$\frac{1}{2}$	578	115.5	24.89	.000234	38.9	2,440	25.30	6.29	31.59	190	12
39	do	1:2:5.19	1:2.01:2.44	19.0	do	7	0	8	11$\frac{1}{8}$	6$\frac{1}{2}$	506	115.1	27.26	.000229	39.6	3,880	29.53	4.84	34.37	206	24
Average												114.2		.000253	38.5				32.14	193	......
53	Granite	1:2:4	1:2.01:3.82	9.2	Wet	7	7	8$\frac{1}{16}$	11$\frac{1}{8}$	6$\frac{1}{2}$	712	150.2	52.61	.000093	43.8	7,950	59.76	6.04	65.80	395	0
54	do	1:2:4	1:2.01:3.82	9.0	do	7	0	7$\frac{15}{16}$	11$\frac{1}{4}$	6$\frac{1}{2}$	630	144.8	52.26	.000079	51.5	8,000	59.72	5.88	65.60	394	12
55	do	1:2:4	1:2.01:3.82	9.0	do	6	6	8	11	6	585	144.9	49.58	.000075	47.6	9,000	55.79	5.20	60.99	366	......
Average												146.6		.000082	47.6				64.13	385	......
51	Granite	1:2:4	1:2.01:3.80	7.3	Med	8	0	8	11$\frac{1}{8}$	7	732	145.7	63.63	.000090	47.5	8,000	72.72	6.93	79.65	478	5
64	do	1:2:4	1:2.01:3.82	8.4	do	7	2	8$\frac{1}{16}$	11$\frac{1}{16}$	6$\frac{1}{2}$	656	147.3	60.95	.000097	45.2	9,000	68.60	6.06	74.66	448	8
65	do	1:2:4	1:2.01:3.82	8.4	do	8	1	8$\frac{1}{8}$	11$\frac{1}{8}$	7	771	153.8	62.65	.000100	49.1	8,000	71.60	7.06	78.66	472	19
Average												148.9		.000096	47.3				77.66	466	......
72	Granite	1:2:4	1:2.01:3.82	6.9	Damp	7	2	8	10$\frac{7}{8}$	6$\frac{1}{2}$	639	147.2	71.34	.000132	45.0	10,000	79.25	6.16	85.41	512	2
73	do	1:2:4	1:2.01:3.82	6.9	do	6	8	8	11	6	626	149.8	74.38	.000129	45.0	13,000	80.58	5.39	85.97	516	5
78	do	1:2:4	1:2.01:3.82	6.9	do	7	2	8	11$\frac{3}{16}$	6$\frac{1}{2}$	673	150.8	74.90	.000125	44.7	11,000	82.39	6.12	88.51	531	24
Average												149.3		.000129	44.9				86.63	520	......

88	Gravel	1:2:4	1:2.01:4.10	9.5	Wet	7	6	8	11	7	640	139.5	46.49	.000073	44.8	6,000	55.79	6.73	62.52	375	16
89	do	1:2:4	1:2.01:4.10	9.5	do	7	9	8⅛	11¼	7	700	142.3	52.52	.000093	42.6	6,000	52.52	6.65	59.17	355	6
90	do	1:2:4	1:2.01:4.10	9.7	do	7	2	8 1/16	11 1/16	6½	634	142.6	45.62	.000063	47.7	7,000	53.22	5.87	59.09	355	6
Average												141.5		.000076	45.0				60.26	362	
100	Gravel	1:2:4	1:2.01:4.10	8.6	Med	7	10	8⅛	11⅛	7	687	142.4	62.72	.000097	44.1	8,390	75.17	6.59	81.76	491	8
101	do	1:2:4	1:2.01:4.10	8.6	do	6	7	8⅛	11 3/16	6	572	137.8	53.10	.000081	45.5	9,000	53.10	4.78	57.88	347	17
102	do	1:2:4	1:2.01:4.10	9.0	do	7	9	8 1/16	11 1/16	7	692	145.5	63.86	.000105	39.1	7,000	63.86	6.85	70.66	424	16
Average												141.9		.000094	42.9				70.10	421	
112	Gravel	1:2:4	1:2.01:4.10	7.6	Damp	7	1	8⅛	11	6½	605	139.3	61.04	.000114	43.6	8,000	61.04	5.71	66.75	400	14
113	do	1:2:4	1:2.01:4.10	7.6	do	7	0	8	11	6½	619	142.9	61.98	.000114	44.1	8,000	61.98	6.00	67.98	408	2
115	do	1:2:4	1:2.01:4.10	7.6	do	6	6	8 1/16	11	6	555	140.6	84.57	.000129	40.0	11,000	84.57	4.91	89.48	537	5
Average												140.9		.000119	42.6				74.74	448	
128	Limestone	1:2:4	1:2.01:3.91	10.8	Wet	7	2	8 1/16	11 1/16	6½	645	145.0	60.82	.000101	50.0	8,660	65.84	5.96	71.80	431	7
129	do	1:2:4	1:2.01:3.91	10.8	do	6	11	8	11¼	6	612	139.1	71.11	.000112	49.1	12,000	71.11	4.82	75.93	456	19
130	do	1:2:4	1:2.01:3.91	11.0	do	6	11	8	11⅜	6	623	142.0	57.96	.000105	43.2	10,930	63.34	4.79	68.13	409	3
Average												142.0		.000106	47.4				71.95	432	
141	Limestone	1:2:4	1:2.01:3.91	10.0	Med	7	0	8 1/16	11 1/16	6½	630	143.2	68.42	.000130	47.3	9,720	73.88	5.99	79.87	479	15
142	do	1:2:4	1:2.01:3.91	10.0	do	7	9	8 1/16	11 1/16	7	698	146.1	63.86	.000102	50.0	8,000	72.98	6.91	79.89	479	9
143	do	1:2:4	1:2.01:3.91	10.0	do	6	9	8	11 1/16	6	608	147.8	73.54	.000145	42.7	12,000	73.54	5.11	78.65	472	1
Average												145.7		.000126	46.7				79.47	477	
150	Limestone	1:2:4	1:2.01:3.91	8.4	Damp	6	11	8 1/16	11⅛	6	623	144.2	84.18	.000138	44.5	15,000	90.19	4.97	95.16	571	14
151	do	1:2:4	1:2.01:3.91	8.4	do	6	11	8	10 13/16	6	607	143.2	83.40	.000145	45.0	13,000	83.40	5.17	88.57	531	9
152	do	1:2:4	1:2.01:3.91	8.4	do	7	9	8	10 15/16	7	686	143.5	65.84	.000120	46.8	8,000	75.24	7.00	82.29	494	16
Average												143.6		.000134	45.4				88.67	532	

TABLE 9.—*Tests of concrete beams of variable span*—Continued.

TESTED AT THIRTEEN WEEKS.

Register No.	Aggregate.	Proportion. Volume.	Proportion. Weight.	Water (per cent).	Consistency.	Dimensions of beam. Length. Ft.	Length. In.	Section (inches). Wide.	Section (inches). Deep.	Span (ft.).
1	2	3	4	5	6	7	8	9	10	11
2	Cinder	1:2:4.86	1:2.02:2.29	22.15	Wet	7	9	8⅛	11 3/16	7
8	do	1:2:4.79	1:2.02:2.25	22.3	do	7	8	8	11	7
9	do	1:2:4.79	1:2.02:2.25	22.0	do	8	3	8	11⅛	7½
Average										
3	Cinder	1:2:5.13	1:2.02:2.41	21.4	Med	7	4	8⅛	11	6½
33	do	1:2:5.21	1:2.01:2.45	21.0	do	7	3	8⅛	11 1/16	6½
34	do	1:2:5.21	1:2.01:2.45	20.0	do	6	8	8	11⅛	6
Average										
40	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	8	1	8	11 3/16	7½
41	do	1:2:5.19	1:2.01:2.44	19.0	do	7	9	8	11	7
42	do	1:2:5.19	1:2.01:2.44	18.9	do	6	9	8	11	6
Average										
56	Granite	1:2:4	1:2.01:3.82	8.7	Wet	7	10	8¼	11 3/16	7
57	do	1:2:4	1:2.01:3.82	8.7	do	6	9	8	11	6
58	do	1:2:4	1:2.01:3.82	9.0	do	7	0	8 1/16	11 1/16	6½
Average										
68	Granite	1:2:4	1:2.01:3.82	8.2	Med	8	0	8 1/16	11⅜	7½
69	do	1:2:4	1:2.01:3.82	8.2	do	6	11	8	11½	6
70	do	1:2:3.97	1:2.01:3.78	8.6	do	6	10	8 1/16	11⅝	6
Average										
79	Granite	1:2:4	1:2.01:3.82	6.9	Damp	7	10	8	11	7
80	do	1:2:4	1:2.01:3.82	7.0	do	7	3	8 1/16	11 5/16	6½
81	do	1:2:4	1:2.01:3.82	7.0	do	6	6	7 15/16	10 15/16	6
Average										

Register No.	Weight (pounds). Total.	Weight (pounds). Per cubic foot.	Final deformeters. $\frac{M}{bd^2}$ (total).	Final deformeters. Unit elongation, lower outer fiber.	Final deformeters. Position neutral axis.	Maximum applied. Load.	Maximum applied. $\frac{M}{bd^2}$ (center).	Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$	Distance of break from center (inches).
1	12	13	14	15	16	17	18	19	20	21	22
2	572	118.4	31.87	0.000121	44.1	4,000	35.41	5.54	40.95	246	20
8	554	116.6	29.75	.000165	40.8	3,600	33.47	5.72	39.19	235	11
9	590	115.3	33.94	.000248	35.0	3,460	36.70	6.34	43.04	258	18
Average		116.8		.000178	40.0				41.06	246	
3	519	114.2	33.57	.000178	41.3	4,800	36.62	4.73	41.35	248	19
33	513	114.8	27.16	.000203	40.2	4,000	30.17	4.69	34.86	209	20
34	477	114.4	33.93	.000340	30.9	5,600	33.93	4.07	38.00	228	12
Average		114.5		.000240	37.5				38.07	228	
40	584	114.3	33.55	.000275	36.8	3,200	33.55	6.36	39.91	239	4
41	560	116.8	33.47	.000446	30.4	3,600	33.47	5.70	39.17	235	1
42	483	115.9	29.75	.000276	36.9	5,200	32.23	4.15	36.38	218	10
Average		115.7		.000332	34.7				38.49	231	
56	723	149.1	70.80	.000092	48.1	9,000	79.65	6.84	86.49	519	6
57	623	149.7	74.38	.000098	48.6	12,700	78.72	5.29	84.01	504	0
58	646	148.7	76.02	.000131	46.5	10,000	76.02	6.14	82.16	493	9
Average		149.2		.000107	47.7				84.22	505	
68	763	149.2	70.46	.000104	45.1	7,590	76.40	7.25	83.65	502	10
69	660	151.9	79.39	.000126	43.1	14,000	79.39	4.96	84.35	506	14
70	563	145.0	82.60	.000123	45.9	15,630	86.07	4.20	90.27	542	20
Average		148.7		.000118	44.7				86.09	517	
79	699	144.5	83.68	.000129	46.5	10,000	92.98	6.96	99.94	600	21
80	669	146.9	87.22	.000145	42.9	13,000	94.50	5.83	100.33	602	0
81	580	143.9	82.14	.000147	44.2	14,000	88.46	5.26	93.72	562	5
Average		145.1		.000140	44.5				98.00	588	

91	Gravel	1:2:4	1:2.01:4.10	9.7	Wet	7	0	$7\frac{15}{16}$	$11\frac{3}{8}$	$6\frac{1}{2}$	625	141.9	51.12	.000067	48.0	7,000	51.12	5.71	56.83	341	4
92	do	1:2:4	1:2.01:4.10	9.9	do	8	6	8	$11\frac{1}{8}$	8	758	145.2	60.60	.000088	46.4	5,570	67.52	8.95	76.47	459	2
93	do	1:2:4	1:2.01:4.10	9.9	do	7	5	8	$11\frac{3}{16}$	$6\frac{1}{2}$	668	143.7	59.92	.000081	48.9	9,000	67.41	5.83	73.24	439	0
Average												143.6		.000079	47.8				68.85	413	
103	Gravel	1:2:4	1:2.01:4.10	9.0	Med	7	8	8	11	7	690	146.5	74.38	.000121	42.2	8,000	74.38	7.05	81.43	489	21
104	do	1:2:4	1:2.01:4.10	9.0	do	7	2	8	$11\frac{3}{16}$	$6\frac{1}{2}$	634	143.6	67.41	.000082	48.4	10,000	74.90	5.78	80.68	484	15
105	do	1:2:4	1:2.01:4.10	9.0	do	6	8	8	11	6	585	143.3	74.38	.000116	45.1	12,000	74.38	5.05	79.43	477	22
Average												144.5		.000106	45.2				80.51	483	
116	Gravel	1:2:4	1:2.01:4.10	7.6	Damp	6	10	8	11	6	599	142.7	68.19	.000159	38.0	12,000	74.39	5.01	79.40	476	8
117	do	1:2:4	1:2.01:4.10	8.0	do	6	9	$7\frac{15}{16}$	$11\frac{1}{16}$	6	597	145.0	74.12	.000094	48.6	13,600	80.30	5.06	85.36	512	20
118	do	1:2:4	1:2.01:4.10	8.1	do	8	6	8	$10\frac{7}{8}$	8	732	144.1	63.42	.000082	48.4	5,960	75.60	9.05	84.65	508	6
Average												143.9		.000112	45.0				83.14	499	
131	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	6	11	$8\frac{1}{8}$	11	6	633	147.6	73.24	.000101	49.5	13,000	79.35	5.12	84.47	507	22
132	do	1:2:4	1:2.01:3.91	11.0	do	7	4	$7\frac{15}{16}$	$11\frac{1}{8}$	$6\frac{1}{2}$	660	147.7	83.99	.000121	46.2	11,000	83.99	5.96	89.95	540	14
133	do	1:2:4	1:2.01:3.91	11.0	do	8	1	8	$11\frac{3}{16}$	$7\frac{1}{2}$	734	146.6	62.91	.000095	46.1	6,950	72.88	7.91	80.79	485	16
Average												147.3		.000106	47.3				85.07	510	
126	Limestone	1:2:4	1:2.01:3.91	10.4	Med	6	6	8	11	6	575	143.5	80.58	.000113	51.8	13,000	80.58	5.12	85.70	514	9
127	do	1:2:4	1:2.01:3.91	10.4	do	6	9	8	$11\frac{3}{16}$	6	623	146.4	83.89	.000127	48.3	14,000	83.89	5.11	89.00	534	0
140	do	1:2:4	1:2.01:3.91	10.0	do	7	4	$7\frac{15}{16}$	$11\frac{1}{4}$	$6\frac{1}{2}$	660	146.1	74.66	.000105	50.0	10,640	79.43	5.82	85.25	512	7
Average												145.3		.000115	50.0				86.65	520	
153	Limestone	1:2:4	1:2.01:3.91	8.4	Damp	7	4	$7\frac{15}{16}$	$10\frac{15}{16}$	$6\frac{1}{2}$	649	144.0	78.98	.000147	42.6	10,000	78.98	6.06	85.04	510	17
154	do	1:2:4	1:2.01:3.91	8.4	do	8	4	$7\frac{15}{16}$	11	$7\frac{1}{2}$	737	146.1	76.53	.000137	44.8	7,000	76.53	7.99	84.52	507	3
155	do	1:2:4	1:2.01:3.91	8.4	do	7	9	$8\frac{1}{16}$	11	7	692	146.3	73.80	.000112	47.6	8,000	73.80	6.93	80.73	484	18
Average												145.5		.000132	45.0				83.43	501	

TABLE 9.—*Tests of concrete beams of variable span*—Continued.

TESTED AT TWENTY-SIX WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Dimensions of beam.				Span (ft.).	Weight (pounds).		Final deformeters.			Maximum applied.		Own weight + deformeters $\frac{M}{bd^2}$ (center).	Maximum total $\frac{M}{bd^2}$ (center).	Modulus of rupture $\frac{6M}{bd^2}$.	Distance of break from center (inches).
		Volume.	Weight.			Length. Ft.	Length. In.	Section (inches). Wide.	Section (inches). Deep.		Total.	Per cubic foot.	$\frac{M}{bd^2}$ (total).	Unit elongation, lower outer fiber.	Position neutral axis.	Load.	$\frac{M}{bd^2}$ (center).				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
12	Cinder	1:2:4.79	1:2.02:2.25	22.4	Wet	6	11	$8\frac{1}{16}$	$11\frac{1}{16}$	6	495	115.9	39.52	0.000266	38.0	6,670	40.56	4.04	44.60	268	21
15	do	1:2:4.79	1:2.02:2.25	22.4	do	7	5	8	$10\frac{7}{8}$	$6\frac{1}{2}$	513	114.2	35.67	.000171	44.2	5,000	39.63	4.80	44.43	267	21
16	do	1:2:5.06	1:2.02:2.38	21.3	do	6	8	$7\frac{15}{16}$	11	6	467	112.8	40.60	.000259	40.6	6,500	40.60	4.11	44.71	268	16
Average												114.3		.000232	40.9				44.58	268	
5	Cinder	1:2:4.79	1:2.02:2.25	21.7	Med.	7	0	$8\frac{1}{16}$	$11\frac{3}{16}$	6	506	117.2	48.31	.000232	43.5	6,500	48.31	4.75	53.06	318	11
6	do	1:2:4.79	1:2.02:2.25	21.7	do	7	4	$8\frac{1}{16}$	11	$6\frac{1}{2}$	525	116.0	38.44	.000193	42.9	5,500	42.28	4.82	47.10	283	9
35	do	1:2:5.21	1:2.01:2.45	20.0	do	6	10	8	11	6	489	116.1	34.10	.000211	40.4	5,600	34.71	4.13	38.84	233	24
Average												116.4		.000212	42.3				46.33	278	
43	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	7	0	$8\frac{1}{8}$	$11\frac{1}{16}$	$6\frac{1}{2}$	490	111.3	41.48	.000327	39.0	5,600	42.24	4.68	46.92	282	17
44	do	1:2:5.19	1:2.01:2.44	19.0	do	7	0	$8\frac{1}{8}$	$11\frac{1}{8}$	$6\frac{1}{2}$	495	114.0	37.29	.000264	39.2	5,350	39.90	4.67	44.57	267	3
45	do	1:2:5.19	1:2.01:2.44	18.5	do	6	10	$8\frac{1}{8}$	$11\frac{1}{16}$	6	478	111.8	39.22	.000290	38.1	6,500	39.22	3.94	43.16	259	14
Average												112.4		.000294	38.8				44.88	269	
59	Granite	1:2:4	1:2.01:3.82	9.0	Wet	8	4	$8\frac{1}{16}$	$11\frac{5}{16}$	$7\frac{1}{2}$	782	145.2	81.42	.000124	47.8	8,000	81.42	7.87	89.29	536	0
60	do	1:2:4	1:2.01:3.82	8.8	do	6	9	$7\frac{7}{8}$	$11\frac{7}{16}$	6	639	151.9	81.56	.000114	46.4	14,950	87.09	5.09	92.18	553	8
61	do	1:2:4	1:2.01:3.82	9.0	do	6	7	8	$11\frac{1}{8}$	6	623	150.3	78.78	.000121	45.8	13,550	82.11	5.33	87.44	525	19
Average												149.1		.000120	46.7				89.64	538	
71	Granite	1:2:3.97	1:2.01:3.78	8.6	Med.	7	2	$8\frac{1}{16}$	$11\frac{7}{16}$	$6\frac{1}{2}$	689	149.4	85.36	.000112	48.0	12,000	85.36	5.95	91.31	548	22
74	do	1:2:4	1:2.01:3.82	8.4	do	7	9	$8\frac{1}{16}$	$11\frac{3}{16}$	7	727	150.5	89.18	.000132	45.0	10,000	89.18	7.02	96.20	577	15
75	do	1:2:4	1:2.01:3.82	8.4	do	6	8	8	$11\frac{3}{16}$	6	615	147.0	83.90	.000130	44.5	14,000	83.90	5.12	89.02	534	22
Average												149.0		.000125	45.8				92.18	553	
82	Granite	1:2:4	1:2.01:3.82	7.0	Damp.	8	1	$8\frac{1}{16}$	$11\frac{1}{16}$	$7\frac{1}{2}$	740	147.5	85.13	.000123	47.1	8,900	94.70	8.09	102.79	617	16
83	do	1:2:4	1:2.01:3.82	7.0	do	7	9	$8\frac{1}{8}$	$11\frac{1}{8}$	7	709	146.1	80.56	.000123	42.8	10,000	89.50	6.88	96.28	578	7
84	do	1:2:4	1:2.01:3.82	7.1	do	6	10	$8\frac{1}{16}$	$11\frac{5}{16}$	6	647	146.9	87.22	.000132	45.8	15,550	90.42	5.06	95.48	573	16
Average												146.8		.000126	45.2				98.22	589	

94	Gravel	1:2:4	1:2.01:4.10	9.9	Wet	7	8	8$\frac{1}{16}$	11$\frac{3}{8}$	7	678	136.4	69.02	.000087	51.9	9,000	77.64	6.43	84.07	504	6
95	do	1:2:4	1:2.01:4.10	9.9	do	7	8	8	11$\frac{5}{16}$	7	672	139.0	70.32	.000096	48.2	8,000	70.32	6.50	76.82	461	14
96	do	1:2:4	1:2.01:4.10	9.9	do	7	8	8$\frac{1}{8}$	11$\frac{5}{16}$	7	690	140.5	60.59	.000097	43.5	7,000	60.59	6.57	67.16	403	10
Average												138.6		.000093	47.9				76.02	456	
106	Gravel	1:2:4	1:2.01:4.10	9.1	Med.	6	10	8	11$\frac{1}{16}$	6	599	142.1	67.42	.000094	47.6	12,000	73.55	4.96	78.51	471	17
107	do	1:2:4	1:2.01:4.10	9.1	do	6	7	8	11	6	582	138.0	80.58	.000114	45.5	14,000	86.78	5.10	91.88	551	16
108	do	1:2:4	1:2.01:4.10	9.0	do	7	8	8	11$\frac{1}{8}$	7	684	142.7	63.63	.000090	45.9	7,920	72.00	6.84	78.84	473	5
Average												140.9		.000099	46.3				83.08	498	
119	Gravel	1:2:4	1:2.01:4.10	8.1	Damp.	6	10	8$\frac{1}{16}$	10$\frac{15}{16}$	6	599	141.5	74.65	.000100	49.5	12,620	78.50	5.03	83.53	501	8
120	do	1:2:4	1:2.01:4.10	8.1	do	6	9	8$\frac{1}{16}$	11	6	592	140.7	67.65	.000105	49.2	11,850	72.88	5.00	77.88	467	3
121	do	1:2:4	1:2.01:4.10	8.1	do	7	3	8$\frac{1}{8}$	11$\frac{1}{16}$	6	636	141.8	75.43	.000119	44.0	10,900	82.22	5.79	88.01	528	14
Average												141.3		.000108	47.6				83.14	499	
134	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	6	7	8$\frac{1}{16}$	11$\frac{1}{8}$	6	603	146.4	66.14	.000100	50.5	12,000	72.15	5.12	77.27	464	4
135	do	1:2:4	1:2.01:3.91	11.0	do	9	0	8	11$\frac{1}{4}$	8	824	144.5	59.26	.000092	49.1	6,000	71.12	8.87	79.99	480	14
136	do	1:2:4	1:2.01:3.91	11.0	do	7	8	8	11$\frac{1}{4}$	7	702	145.8	71.11	.000105	48.3	9,000	80.00	6.85	86.85	521	6
Average												145.6		.000099	49.3				81.37	488	
144	Limestone	1:2:4	1:2.01:3.91	10.0	Med.	7	3	8$\frac{1}{16}$	11$\frac{1}{8}$	6$\frac{1}{2}$	658	144.0	82.68	.000118	48.1	12,000	90.20	5.93	96.13	577	9
145	do	1:2:4	1:2.01:3.91	10.0	do	8	0	8	11$\frac{3}{16}$	7$\frac{1}{2}$	732	146.7	73.41	.000108	47.1	8,000	83.90	7.98	91.88	551	16
258	do	1:2:4	1:2.01:3.91	10.0	do	8	5	8$\frac{1}{16}$	11$\frac{5}{16}$	7$\frac{1}{2}$	770	145.1	81.41	.000102	51.6	8,000	81.41	7.66	89.07	534	6
Average												145.3		.000109	48.9				92.36	554	
158	Limestone	1:2:4	1:2.01:3.91	8.6	Damp.	6	8	8	11$\frac{1}{8}$	6	621	149.2	84.84	.000127	47.5	15,000	90.90	5.23	96.13	577	21
259	do	1:2:4	1:2.01;3.91	8.6	do	8	3	8$\frac{1}{16}$	11$\frac{1}{4}$	7$\frac{1}{2}$	762	149.4	92.61	.000128	48.6	9,000	92.61	7.86	100.47	603	0
260	do	1:2:4	1:2.01:3.91	8.6	do	6	7	8$\frac{1}{16}$	11$\frac{1}{8}$	6	613	147.3	97.41	.000137	47.4	16,200	97.41	5.20	102.61	616	14
Average												148.6		.000131	47.8				99.74	632	

TABLE 10.—*Compression tests of concrete cylinders and cubes accompanying beams.*

TESTED AT FOUR WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Cylinders.						Cubes.				Stress ratio of cylinders to cubes.
		Volume.	Weight.			Dimensions (inches). Diameter.	Dimensions (inches). Length.	Weight (pounds per cubic foot).	Maximum unit stress.	Initial modulus of elasticity.	Range of linear values.	Dimensions (inches). Base.	Dimensions (inches). Height.	Weight (pounds per cubic foot).	Maximum unit stress.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
18	Cinder	1:2:5.06	1:2.02:2.38	21.6	Wet	8.00	16.00		1,243	1,017,000	200	6.00×6.00	5.94		1,394	0.892
19	do	1:2:5.06	1:2.02:2.38	21.8	do	8.00	16.00		1,000	1,337,000	250	6.00×6.00	5.94		1,200	.833
21	do	1:2:5.06	1:2.02:2.38	21.6	do	8.00	16.00		1,000	1,355,000	350	6.00×6.00	6.00		1,173	.853
Average									1,081	1,236,000	270				1,256	.859
24	Cinder	1:2:5.06	1:2.02:2.38	19.4	Med.	8.00	16.00		1,114	2,020,000	250	6.00×6.00	6.00		1,179	.945
28	do	1:2.06:5.40	1:2.07:2.54	20.4	do	8.00	16.00		1,250	1,000,000	250	6.00×6.00	6.25		1,093	1.144
29	do	1:2.06:5.40	1:2.07:2.54	20.4	do	8.00	16.00		1,240	1,035,000	300	6.00×6.00	6.13		1,302	.952
Average									1,201	1,352,000	270				1,191	1.014
37	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	8.00	16.00		1,055	1,250,000	300	6.00×6.00	6.13		1,541	.685
38	do	1:2:5.19	1:2.01:2.44	19.0	do	8.00	16.00		1,210	1,390,000	250	6.00×6.00	6.13		1,394	.868
39	do	1:2:5.19	1:2.01:2.44	19.0	do	8.00	16.00		1,090	1,225,000	350	6.00×6.00	6.13		1,199	.909
Average									1,118	1,288,000	300				1,378	.821
53	Granite	1:2:4	1:2.01:3.82	9.2	Wet	8.00	16.00	149.3	3,093	3,690,000	700	6.00×6.00	6.00	144.0	3,318	.932
54	do	1:2:4	1:2.01:3.82	9.0	do	8.00	16.00	146.6	2,350	3,020,000	850	6.00×6.00	6.13	146.0	3,151	.746
55	do	1:2:4	1:2.01:3.82	9.0	do	8.00	16.00	150.4	2,607	4,000,000	800	6.00×6.00	6.13	148.9	3,000	.869
Average								148.8	2,683	3,570,000	780			146.3	3,156	.849
51	Granite	1:2:4	1:2.01:3.82	7.3	Med.	8.00	16.00	150.9	3,990	4,100,000	1,000	6.00×6.00	6.00	153.0	4,063	.982
64	do	1:2:4	1:2.01:3.82	8.4	do	7.99	16.05	148.8	3,250	4,640,000	800	6.02×6.02	6.13	147.8	4,251	.765
65	do	1:2:4	1:2.01:3.82	8.4	do	8.07	16.19	146.6	3,199	3,510,000	1,000	6.03×6.03	6.14	146.1	3,954	.809
Average								148.8	3,480	4,083,000	930			149.0	4,089	.852
72	Granite	1:2:4	1:2.01:3.82	6.9	Damp	8.03	15.95	149.8	4,000	4,840,000	1,000	5.98×5.98	6.06	150.5	5,072	.789
73	do	1:2:4	1:2.01:3.82	6.9	do	8.04	16.14	148.7	4,000	4,860,000	1,000	6.03×6.03	6.05	147.3	3,780	1.058
78	do	1:2:4	1:2.01:3.82	6.9	do	8.02	15.97	148.9	4,000	4,960,000	950	5.99×5.99	6.03	145.8	4,703	.851
Average								149.1	4,000	4,890,000	980			147.9	4,518	.899
88	Gravel	1:2:4	1:2.01:4.10	9.5	Wet	8.02	16.24	141.1	2,336	3,850,000	800	5.98×5.98	6.18	141.7	2,757	.847
89	do	1:2:4	1:2.01:4.10	9.5	do	7.99	16.11	138.2	2,087	4,040,000	1,000	6.02×6.02	6.23	138.5	2,342	.891
90	do	1:2:4	1:2.01:4.10	9.7	do	7.99	16.22	141.6	1,758	3,470,000	800	6.04×6.04	6.22	139.0	1,799	.977
Average								140.3	2,060	3,787,000	870			139.7	2,299	.905

100	Gravel	1:2:4	1:2.01:4.10	8.6	Med	8.06	16.09	142.6	3,375	a 6,620,000	1,500	6.02×6.02	6.12	142.1	3,886	.869
101	do	1:2:4	1:2.01:4.10	8.6	do	7.99	16.18	142.7	2,486	3,900,000	1,500	5.97×5.97	6.14	146.1	3,576	.695
102	do	1:2:4	1:2.01:4.10	9.0	do	7.99	16.18	142.7	3,022	3,850,000	1,500	6.02×6.02	6.16	142.2	3,179	.951
Average								142.7	2,961	3,875,000	1,500			143.5	3,547	.838
112	Gravel	1:2:4	1:2.01:4.10	7.6	Damp	8.09	16.04	141.7	3,437	4,640,000	1,000	6.02×6.02	6.09	142.9	4,581	.750
113	do	1:2:4	1:2.01:4.10	7.6	do	8.11	16.15	140.9	a 2,392	3,840,000	1,200	6.03×6.03	6.07	144.9	4,565	
115	do	1:2:4	1:2.01:4.10	7.6	do	8.07	16.08	142.9	3,377	3,730,000	1,400	5.97×5.97	6.02	147.1	4,689	.720
Average								141.8	3,407	4,070,000	1,200			145.0	4,612	.735
128	Limestone	1:2:4	1:2.01:3.91	10.8	Wet	7.99	16.02	147.6	2,741	3,460,000	900	6.06×6.06	6.16	142.3	5,065	.541
129	do	1:2:4	1:2.01:3.91	10.8	do	8.02	16.07	145.5	2,591	3,890,000	1,300	5.99×5.99	6.14	147.1	5,216	.497
130	do	1:2:4	1:2.01:3.91	11.0	do	8.07	16.04	143.2	3,884	3,415,000	1,200	5.98×5.98	6.23	145.5	a 2,307	a 1.684
Average								145.4	3,072	3,588,000	1,130			145.0	5,141	.519
141	Limestone	1:2:4	1:2.01:3.91	10.0	Med	7.99	16.11	145.5	3,889	3,400,000	700	5.98×5.98	6.12	146.1	2,644	1.471
142	do	1:2:4	1:2.01:3.91	10.0	do	7.97	16.08	145.9	2,458	3,700,000	800	6.02×6.02	6.04	143.8	3,315	.742
143	do	1:2:4	1:2.01:3.91	10.0	do	8.01	16.04	146.6	2,382	3,195,000	1,100	6.01×6.02	6.14	143.9	2,965	.803
Average								146.0	2,910	3,432,000	870			144.6	2,975	1.005
151	Limestone	1:2:4	1:2.01:3.91	8.4	Damp	8.03	16.22	146.2	3,171	4,025,000	800	6.03×6.03	6.07	147.8	3,948	.803
152	do	1:2:4	1:2.01:3.91	8.4	do	7.98	16.07	150.8	2,749	4,720,000	500	5.99×5.99	6.05	149.3	4,392	.626
153	do	1:2:4	1:2.01:3.91	8.4	do	8.04	16.12	149.0	2,761	4,025,000	1,200	5.98×5.98	6.06	148.5	4,760	.580
Average								148.7	2,894	4,257,000	830			148.5	4,367	.670

a Not included in average.

TABLE 10.—*Compression tests of concrete cylinders and cubes accompanying beams*—Continued.

TESTED AT THIRTEEN WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Cylinders.						Cubes.				Stress ratio of cylinders to cubes.
		Volume.	Weight.			Dimensions (inches). Diameter.	Dimensions (inches). Length.	Weight (pounds per cubic foot).	Maximum unit stress.	Initial modulus of elasticity.	Range of linear values.	Dimensions (inches). Base.	Dimensions (inches). Height.	Weight (pounds per cubic foot).	Maximum unit stress.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	Cinder	1:2:4.86	1:2.02:2.29	22.15	Wet	8.02	16.00	120.3	1,651	3,500,000	400	6.04×6.04	6.04	115.7	2,037	0.311
8	do	1:2:4.79	1:2.02:2.25	22.3	do	8.02	15.88	117.2	1,963	1,740,000	600	6.04×6.04	6.09	114.8	2,086	.941
9	do	1:2:4.79	1:2.02:2.25	22.0	do	8.01	16.13	111.9	1,678	2,730,000	300	6.02×6.03	6.01	115.8	1,923	.873
Average								116.5	1,764	2,657,000	430			115.4	2,015	.875
3	Cinder	1:2:5.13	1:2.02:2.41	21.4	Med	8.01	15.75	118.7	1,830	3,120,000	400	6.07×6.07	6.04	112.6	1,687	1.085
33	do	1:2:5.21	1:2.01:2.45	21.0	do	8.00	15.99	114.5	1,643	2,030,000	300	5.99×6.04	6.04		2,145	.766
34	do	1:2:5.21	1:2.01:2.45	20.0	do	8.01	16.02	113.7	1,984	1,675,000	500	6.11×6.12	6.07	110.3	1,732	1.146
Average								115.6	1,819	2,275,000	400			111.5	1,855	.999
40	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	8.00	16.15	113.6	1,725	1,940,000	500	5.97×6.05	6.07	114.3	2,009	.859
41	do	1:2:5.19	1:2.01:2.44	19.0	do	8.06	16.15	112.5	1,790	1,460,000	400	6.03×6.06	6.15	114.4	1,806	.991
42	do	1:2:5.19	1:2.01:2.44	18.9	do	8.07	16.03	111.4	1,662	1,505,000	500	5.99×6.03	6.15	114.8	1,769	.940
Average								112.5	1,726	1,635,000	470			114.5	1,861	.930
56 *a*	Granite	1:2:4	1:2.01:3.82	8.7	Wet	8.00	16.10	146.6	3,528	4,840,000	1,300	6.04×6.05	6.27	145.2	4,779	.738
57	do	1:2:4	1:2.01:3.82	8.7	do	8.07	16.15	144.9	3,197	3,690,000	1,200	6.05×6.07	6.25	145.0	4,954	.645
58	do	1:2:4	1:2.01:3.82	9.0	do	7.99	16.00	146.7	3,805	4,320,000	1,300	6.01×6.03	6.04	148.0	4,529	.840
Average								146.1	3,510	4,283,000	1,270			146.1	4,754	.741
68	Granite	1:2:4	1:2.01:3.82	8.2	Med	8.00	16.13	147.9	(*b*)	4,800,000	1,100	6.02×6.06	6.20	149.9	5,099	
69	do	1:2:4	1:2.01:3.82	8.2	do	8.03	16.24	145.8	(*c*)	4,780,000	1,200	6.01×6.01	6.14	148.0	5,372	
70	do	1:2:3.97	1:2.01:3.78	8.6	do	8.01	16.01	147.5	3,777	4,660,000	1,100	6.03×6.05	6.11	146.3	4,504	
Average								147.1		4,747,000	1,130			148.1	4,992	
79	Granite	1:2:4	1:2.01:3.82	6.9	Damp	8.05	16.09	148.2	(*d*)	4,340,000	1,300	6.01×6.02	6.12	148.3	(*e*)	
80	do	1:2:4	1:2.01:3.82	7.0	do	8.03	16.11	148.3	(*c*)	5,280,000	1,200	5.98×6.02	6.03	149.3	5,445	
81	do	1:2:4	1:2.01:3.82	7.0	do	8.08	16.10	147.6	(*f*)	4,470 000	1,000	6.02×6.06	6.11	144.4	(*g*)	
Average								148.0		4,697,000	1,170			147.3		

91	Gravel	1:2:4	1:2.01:4.10	9.7	Wet	8.01	16.37	139.6	2,699	5,360,000	1,000	Cubes not tested.				
92	do	1:2:4	1:2.01:4.10	9.9	do	8.01	16.16	140.9	2,967	5,000,000	1,200					
93	do	1:2:4	1:2.01:4.10	9.9	do	8.03	16.37	139.7	3,195	4,310,000	1,100					
Average								140.1	2,954	4,890,000	1,100					
103	Gravel	1:2:4	1:2.01:4.10	9.0	Med	8.09	16.10	140.7	(h)	5,920,000	900					
104	do	1:2:4	1:2.01:4.10	9.0	do	8.05	16.13	142.3	i3,930	5,300,000	1,200					
105	do	1:2:4	1:2.01:4.10	9.0	do	8.03	16.17	141.1	2,765	4,380,000	1,900					
Average								141.4		5,200,000	1,330					
116	Gravel	1:2:4	1:2.01:4.10	7.6	Damp	8.02	16.15	145.1	(j)	5,140,000	1,400	6.03×6.03	6.01		4,071	
117	do	1:2:4	1:2.01:4.10	8.0	do	8.01	16.16	146.4	(k)	5,140,000	1,400	6.05×6.05	6.10		5,369	
118	do	1:2:4	1:2.01:4.10	8.1	do	8.03	16.18	143.4	(c)	5,200,000	1,100	6.02×6.01	6.05		5,528	
Average								145.0		5,160,000	1,300				4.989	
131	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	8.05	16.23	142.0	3,397	3,700,000	1,000	6.10×6.15	6.07	141.3	4,068	.835
132	do	1:2:4	1:2.01:3.91	11.0	do	8.00	16.12	145.0	3,441	4,240,000	700	6.05×6.05	6.17	142.5	4,179	.823
133	do	1:2:4	1:2.01:3.91	11.0	do	7.99	16.10	145.5	3,318	4,010,000	1,000	6.10×6.06	6.15	141.5	3,776	.879
Average								144.2	3,385	3,983,000	900			141.8	4,008	.846
126 l	Limestone	1:2:4	1:2.01:3.91	10.4	Med	8.03	16.16	147.0	3,508	3,800,000	1,000	6.02×6.03	6.19	143.3	4,004	.876
127 l	do	1:2:4	1:2.01:3.91	10.4	do	8.05	16.11	146.2	3,458	3,960,000	1,100	6.04×6.05	6.19	143.2	3,974	.870
140 l	do	1:2:4	1:2.01:3.91	10.0	do	8.02	16.27	143.5	3,445	4,130,000	800	6.03×6.05	6.18	143.7	3,838	.898
Average								145.6	3,470	3,963,000	970			143.4	3,939	.881
153	Limestone	1:2:4	1:2.01:3.91	8.4	Damp	8.02	16.41	146.7	(j)	4,680,000	1,200	6.01×6.11	6.12	146.1	(m)	
154	do	1:2:4	1:2.01:3.91	8.4	do	8.00	16.22	148.3	(b)	4,500,000	1,000	6.02×6.06	6.17	145.9	5,483	
155	do	1:2:4	1:2.01:3.91	8.4	do	8.02	16.20	149.0	(j)	4,800,000	1,000	6.03×6.03	6.13	147.3	5,451	
Average								148.0		4,660,000	1,070			146.4		

a Cylinder spalled before test.
b Cylinder did not fail at 3,979 unit stress.
c Cylinder did not fail at 3,950 unit stress.
d Cylinder did not fail at 3,929 unit stress.
e Cube did not fail at 5,528 unit stress
f Cylinder did not fail at 3,900 unit stress.
g Cube did not fail at 5,483 unit stress.
h Cylinder did not fail at 3,891 unit stress.
i Cylinder broke after several minutes under load.
j Cylinder did not fail at 3,959 unit stress.
k Cylinder did not fail at 3,969 unit stress.
l Cubes 17 weeks old.
m Cube did not fail at 5,447 unit stress.

TABLE 10.—*Compression tests of concrete cylinders and cubes accompanying beams*—Continued.

TESTED AT TWENTY-SIX WEEKS.

Register No.	Aggregate.	Proportion.		Water (per cent).	Consistency.	Cylinders.						Cubes.				Stress ratio of cylinders to cubes.
		Volume.	Weight.			Dimensions (inches).		Weight (pounds per cubic foot).	Maximum unit stress.	Initial modulus of elasticity.	Range of linear values.	Dimensions (inches).		Weight (pounds per cubic foot).	Maximum unit stress.	
						Diameter.	Length.					Base.	Height.			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12	Cinder	1:2:4.79	1:2.02:2.25	22.4	Wet	7.99	15.95	113.2	1,872	1,720,000	500	6.00×6.00	6.00	114.0	2,350	0.797
15	do	1:2:4.79	1:2.02:2.25	22.4	do	8.00	16.11	113.9	2,090	1,580,000	800	6.00×6.00	6.00	115.0	2,124	.984
16	do	1:2:5.06	1:2.02:2.38	21.3	do	7.98	16.02	114.6	2,100	1,530,000	1,000	6.00×6.00	6.00	115.0	2,486	.845
Average								113.9	2,021	1,610,000	770			114.7	2,320	.875
5	Cinder	1:2:4.79	1:2.02:2.25	21.7	Med	8.01	15.85	113.4	2,481	1,680,000	1,200	6.01×6.03	6.03	115.7	2,950	.841
6	do	1:2:4.79	1:2.02:2.25	21.7	do	7.98	15.91	116.2	2,132	1,535,000	700	6.00×5.99	6.03	116.7	2,633	.810
35	do	1:2:5.21	1:2.01:2.45	20.0	do	8.00	16.10	113.4	1,995	1,640,000	600	6.03×6.03	6.06	111.9	2,712	.736
Average								114.3	2,203	1,618,000	830			114.8	2,765	.796
43	Cinder	1:2:5.19	1:2.01:2.44	19.0	Damp	8.02	16.16	112.2	1,940	1,300,000	700	6.04×6.04	6.02	113.1	2,310	.840
44	do	1:2:5.19	1:2.01:2.44	19.0	do	8.01	16.02	114.2	1,895	1,245,000	600	6.04×6.03	6.14	109.2	2,434	.779
45	do	1:2:5.19	1:2.01:2.44	18.5	do	7.98	16.10	114.8	2,001	1,600,000	600	6.14×6.02	6.02	115.5	2,720	.736
Average								113.7	1,945	1,382,000	630			112.6	2,488	.785
59	Granite	1:2:4	1:2.01:3.82	9.0	Wet	8.03	15.81	147.6	(a)	4,000,000	2,000	6.03×6.00	6.00	146.3	4,768	
60	do	1:2:4	1:2.01:3.82	8.8	do	7.99	15.90	147.1	(b)	4,040,000	1,400	6.01×6.01	6.03	145.8	4,859	
61	do	1:2:4	1:2.01:3.82	9.0	do	8.02	16.02	149.2	(c)	4,130,000	1,700	6.01×6.02	6.03	157.4	4,633	
Average								148.0		4,057,000	1,700			149.8	4,753	
71	Granite	1:2:3.97	1:2.01:3.78	8.6	Med	8.02	16.08	146.8	(c)	4,020,000	2,000	6.13×6.09	6.00	144.7	4,814	
74	do	1:2:4	1:2.01:3.82	8.4	do	8.00	16.11	147.5	(d)	3,800,000	2,200	6.00×5.98	6.12	149.5	4,892	
75	do	1:2:4	1:2.01:3.82	8.4	do	8.00	16.10	147.1	(d)	3,920,000	2,100	6.06×6.01	6.17	145.2	5,142	
Average								147.1		3,913,000	2,100			146.5	4,949	
82	Granite	1:2:4	1:2.01:3.82	7.0	Damp	8.02	16.11	149.9	(c)	4,760,000	2,000	6.00×6.06	6.00		5,410	
83	do	1:2:4	1:2.01:3.82	7.0	do	8.01	16.11	150.3	(e)	4,310,000	2,300	6.00×6.00	6.08	149.0	(f)	
84	do	1:2:4	1:2.01:3.82	7.1	do	8.00	16.02	149.1	(g)	4,220,000	2,000	6.02×6.02	6.04	147.0	5,519	
Average								149.8		4,430,000	2,100			148.0		
94	Gravel	1:2:4	1:2.01:4.10	9.9	Wet	8.00	16.09	138.4	h3,461	4,090,000	1,900	6.00×6.00	6.21	137.2	3,793	.913
95	do	1:2:4	1:2.01:4.10	9.9	do	8.01	16.15	139.1	3,431	3,660,000	2,200	6.05×6.01	6.22	138.5	3,699	.927
96	do	1:2:4	1:2.01:4.10	9.9	do	8.01	16.15	138.3	3,565	4,400,000	1,100	6.00×6.04	6.17	138.1	3,949	.903
Average								138.6	3,486	4,050,000	1,730			137.9	3,814	.914

106	Gravel	1:2:4	1:2.01:4.10	9.1	Med	8.01	16.17	142.4	(e)	4,760,000	2,400	6.00×6.00	6.15	142.5	5,176	
107	do	1:2:4	1:2.01:4.10	9.1	do	8.00	16.14	142.7	(g)	4,740,000	(i)	6.03×6.03	6.20	140.9	4,810	
108	do	1:2:4	1:2.01:4.10	9.0	do	8.01	16.12	143.9	(e)	4,480,000	2,600	6.06×6.06	6.02	142.6	4,439	
Average								143.0		4,660,000	2,500			142.0	4,808	
119	Gravel	1:2:4	1:2.01:4.10	8.1	Damp	8.00	16.02	145.9	(d)	5,400,000	2,300	6.00×6.00	6.00	144.0	5,472	
120	do	1:2:4	1:2.01:4.10	8.1	do	8.03	16.02	147.0	(a)	4,480,000	1,700	6.00×6.00	6.00	144.0	4,972	
121	do	1:2:4	1:2.01:4.10	8.1	do	8.00	16.00	147.5	(g)	4,740,000	2,400	6.00×6.00	6.00	146.0	4,208	
Average								146.8		4,873,000	2,130			144.7	4,884	
134	Limestone	1:2:4	1:2.01:3.91	11.0	Wet	8.02	16.00	144.3	3,062	3,980,000	1,600	6.00×6.00	6.00	148.0	3,167	.967
135	do	1:2:4	1:2.01:3.91	11.0	do	8.00	16.03	145.8	3,113	3,080,000	1,600	6.00×6.00	6.00	144.0	3,860	.807
136	do	1:2:4	1:2.01:3.91	11.0	do	8.03	16.06	143.4	3,473	3,210,000	1,800	6.00×6.00	6.00	148.0	3,354	1.035
Average								144.5	3,216	3,423,000	1,670			146.7	3,460	.936
144	Limestone	1:2:4	1:2.01:3.91	10.0	Med	8.00	16.05	146.7	3,567	4,030,000	1,500	6.00×6.00	6.00	150.0	3,300	1.081
145	do	1:2:4	1:2.01:3.91	10.0	do	8.02	16.13	145.2	3,902	3,640,000	2,000	6.00×6.00	6.00	148.0	3,443	1.133
258	do	1:2:4	1:2.01:3.91	10.0	do	8.00	16.06	146.8	3,605	4,160,000	1,200	6.01×6.01	6.07	147.3	4,935	.731
Average								146.2	3,691	3,943,000	1,570			148.4	3,896	.982
158	Limestone	1:2:4	1:2.01:3.91	8.6	Damp	8.13	16.13	145.7	(j)	3,690,000	2,000	6.00×6.00	6.00	150.0	4,218	
259	do	1:2:4	1:2.01:3.91	8.6	do	7.99	16.19	149.0	(b)	4,400,000	1,400	5.96×6.05	6.09	148.0	5,325	
260	do	1:2:4	1:2.01:3.91	8.6	do	8.00	16.19	148.4	(d)	4,220,000	1,900	6.01×5.99	6.03	147.8	5,532	
Average								147.7		4,310,000	1,770			148.6	5,025	

a Cylinder did not break at 3,950 unit stress.
b Cylinder did not break at 3,989 unit stress.
c Cylinder did not break at 3,959 unit stress.
d Cylinder did not break at 3,979 unit stress.
e Cylinder did not break at 3,969 unit stress.
f Cube did not break at 5,556 unit stress.
g Cylinder did not break at 3,978 unit stress.
h Cylinder stress approximate.
i Machine vibrated compressometer.
j Cylinder did not break at 3,858 unit stress.

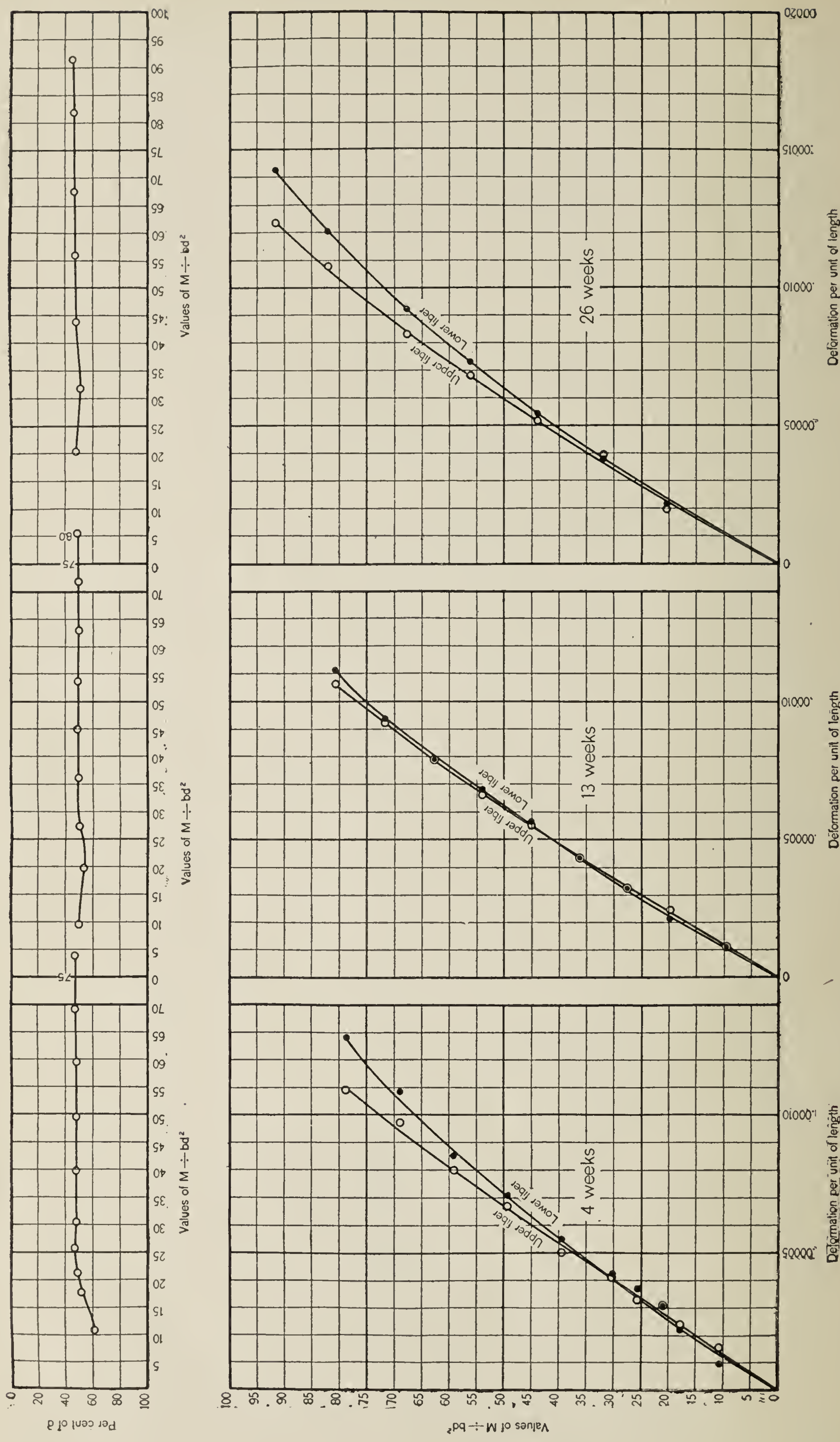


FIG. 11.—Characteristic deformation curves for flexure, granite concrete of medium consistency; ages 4, 13, and 26 weeks.

BEAMS OF VARIABLE SPAN.

The detailed results of tests of the beams of variable span are given in Table 9 (pp. 42–47), and some of the results are graphically shown in figs. 2–5. The information given in columns 1–14, 17, 18, 21, and 22 of the table is identical in character with that given in the corresponding columns of Table 8.

Column 15 contains the unit elongation of the lower outer fiber for the applied load only, since the short beams were not suspended for zero total deformations as were the long beams. The values of the unit elongation, including that due to the weight of the beam and the deformeters, may be approximated by increasing the values in column 15 by an amount obtained from the averages in column 12, Table 8, on the assumption that the elongation is directly proportional to the values for $\frac{M}{bd^2}$, which is approximately true for values below those for the weight of the beam plus the weight of the deformeters. The values for $\frac{M}{bd^2}$ for own weight and deformeters are given in column 19 and, as may be seen by comparing with the maximum total values in column 20, are in the majority of cases but a small percentage of the total.

Column 16 gives the position of the neutral axis in percentage of the depth below the top of the beam. These values are not strictly comparable with those in column 15, Table 8, since they are based on deformations due to the applied load alone.

CYLINDERS AND CUBES.

The detailed results of the compression tests of cylinders 8 inches in diameter by 16 inches in length and of 6-inch cubes are given in Table 10. Some of the results are also graphically shown in figs. 2–9.

Columns 1–6 contain the same kind of information as is given for the beams in the corresponding columns of Tables 8 and 9.

Columns 7 and 8 and columns 13 and 14 show the dimensions of the cylinders and cubes, respectively, in inches.

Columns 9 and 15 show the weight in pounds per cubic foot, as figured from the dimensions and the actual weight of each cylinder and cube when tested.

Columns 10 and 16 show the ultimate strength of each cylinder and cube in pounds per square inch.

The initial modulus of elasticity (given in column 11) was obtained from a curve showing the relation between the unit gross deformation and the compressive stress in pounds per square inch, by drawing a line tangent to the curve at the origin or where possible coincident with the straight line or initial part of the curve. The range in pounds

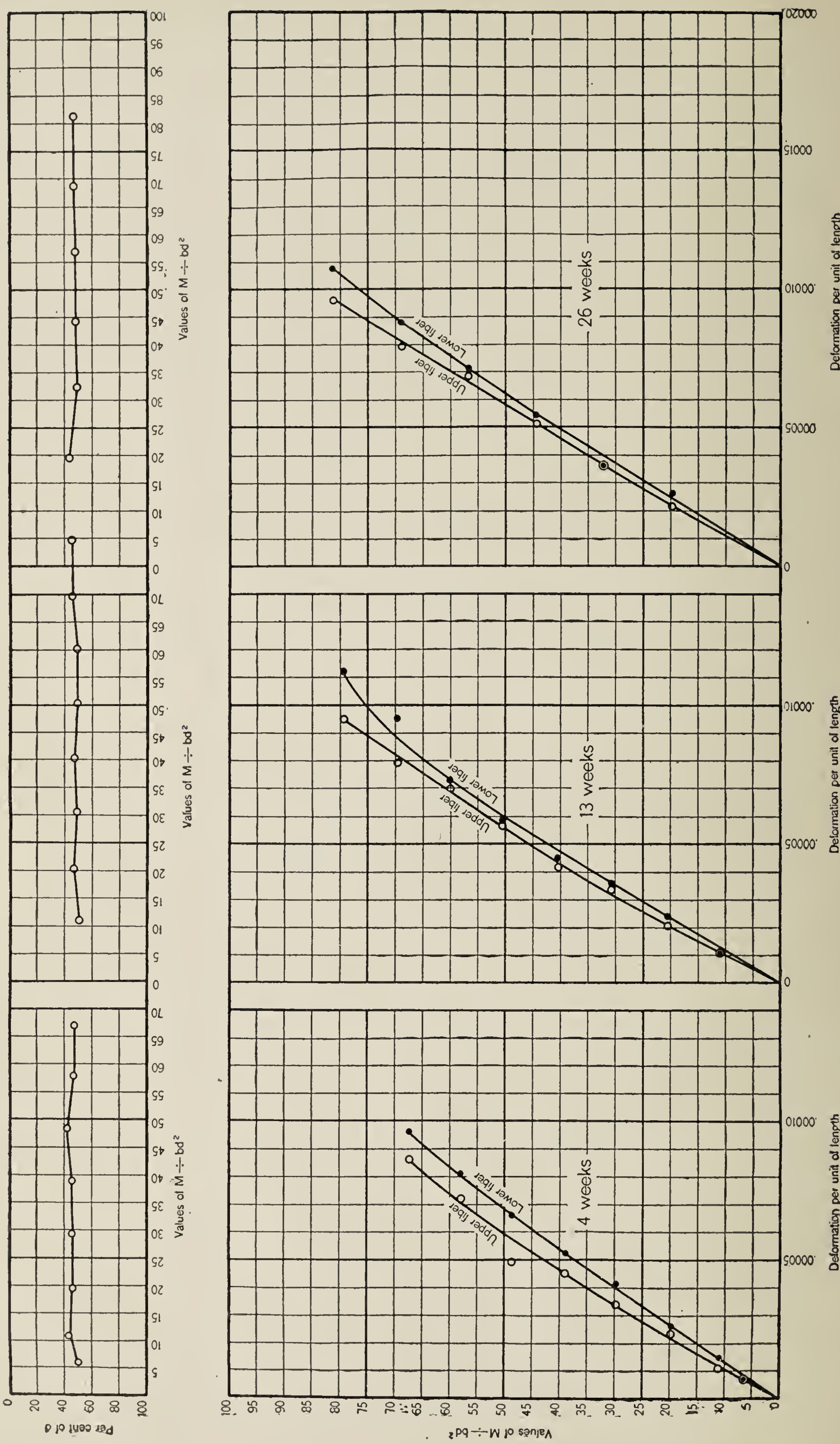


FIG. 12.—Characteristic deformation curves for flexure, gravel concrete of medium consistency; ages 4, 13, and 26 weeks.

per square inch within which the line drawn coincides with the curve is also shown (column 12).

Column 17 gives the ratio of the ultimate strength of the cylinders to that for the cubes.

It is to be regretted that the capacity of the machines composing the equipment was exceeded by the strength of many of the cylinders and cubes at the time these tests were made, preventing the accurate determination of the actual growth of strength with age. There is, however, in almost every case a substantial increase in strength with age.

The effect of consistency on the strength is much more noticeable, and leads to much more uniform results for the cubes and cylinders than for the beams. This would lead one to believe that the effect of consistency is much more noticeable and much more uniform on the compressive strength of concrete than on the tensile strength.

Owing to a breakdown of the engine it became necessary to apply the load by hand for a number of tests. The beams and cylinders, being deemed the most important, were tested in this way, but because of the difficulty of turning the gears of the testing machine by hand the testing of the cubes was omitted.

ILLUSTRATIVE DIAGRAMS.

Figs. 2, 3, 4, and 5 show graphically the effect of age and consistency on the ultimate compressive strength of cinder, granite, gravel, and limestone concretes, as obtained from the tests on the cylinders and cubes and in the modulus of rupture as given by the tests in the beams of constant and variable span.

Figs. 6, 7, 8, and 9 show graphically several characteristic compression-stress deformation curves obtained from tests on the cylinders, while figs. 10, 11, 12, and 13 show the deformation curves for a few of the beams of 12-foot span.

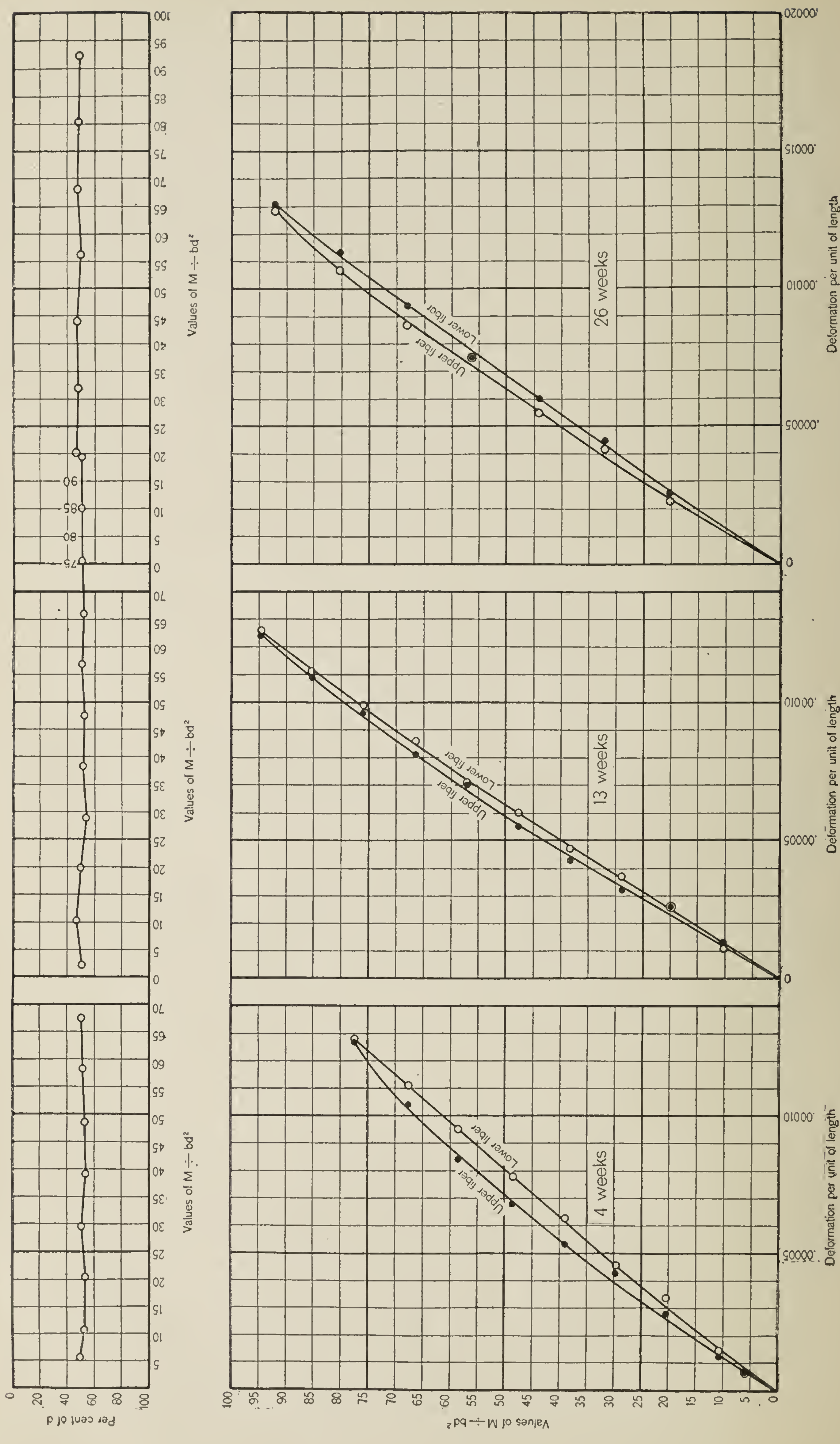


FIG. 13.—Characteristic deformation curves for flexure, limestone concrete of medium consistency; ages 4, 13, and 26 weeks.

SURVEY PUBLICATIONS ON TESTS OF STRUCTURAL MATERIALS.

The following reports, published by the Geological Survey, relate to structural materials, etc.:

BULLETIN 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 8°. 83 pp., 11 pls.

BULLETIN 243.* Cement materials and industry of the United States, by E. C. Eckel. 1905. 8°. 395 pp., 15 pls. 65c.

BULLETIN 260.* The American cement industry, pp. 496–505. 1905. 40c.

BULLETIN 324. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials, by G. K. Gilbert, R. L. Humphrey, J. S. Sewell, and Frank Soulé. 1907. 170 pp.

BULLETIN 329. Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo., by R. L. Humphrey. 1908. 85 pp.

BULLETIN 331. Portland cement mortars and their constituent materials; results of tests made at the structural-materials testing laboratories, St. Louis, Mo., by R. L. Humphrey and William Jordan, jr. 1908. 130 pp.

WATER-SUPPLY PAPER 143. Experiments on steel-concrete pipes on a working scale, by J. H. Quinton. 1905. 8°. 61 pp., 4 pls.

MINERAL RESOURCES U. S. FOR 1901,* 1902, 1903,* 1904, AND 1905.* Cement. A series of annual articles on the cement industry and the production of cement in the United States, by L. L. Kimball. 50c. for each volume.

MINERAL RESOURCES U. S. FOR 1906, pp. 897–905. Advances in cement technology, 1906, by E. C. Eckel.

Reports marked with an asterisk (*) are out of stock, but may be had from the Superintendent of Documents, Washington, D. C., at the prices named. The others will be sent free to anyone interested on application to The Director, United States Geological Survey, Washington, D. C.

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